13:22:21 OCA PAD INITIATION - PROJECT HEADER INFORMATION 04/10/88

Active

Project #: E-25-M42 Cost share #: Rev #: 0
Center # : R6467-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: 19X-SB729C Mod #: Document : SUBCONT
Prime #: DE-AC05-84OR21400 Contract entity: GTRC

Subprojects ? : N
Main project #:

Project unit: ME Unit code: 02.010.126
Project director(s):
EICHHOLZ G G ME

Sponsor/division names: OAK RIDGE NAT'L LAB / MARTIN MARIETTA
Sponsor/division codes: 240 / 001

Award period: 880201 to 881031 (performance) 881031 (reports)

Sponsor amount	New this change	Total to date
Contract value	25,184.00	25,184.00
Funded	25,184.00	25,184.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: DOSE-RATE DEPENDENCE OF THERMOLUMINESCENT DOSIMETERS / DE-AC05-84021400

PROJECT ADMINISTRATION DATA

OCA contact: John B. Schonk 894-4820

Sponsor technical contact	Sponsor issuing office
JAMES S. BOGARD	JOHN E. SCHULTZ (615)576-0251
MARTIN MARIETTA ENERGY SYSTEMS P.O. BOX M OAK RIDGE, TN 37831	SAME

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : DPAS GOVT supplemental sheet
Equipment title vests with: Sponsor X GIT

Administrative comments -
PROJECT INITIATION
PROJECT IS ADMINISTERED UNDER THE USUAL MARTIN MARIETTA/ OAK RIDGE T'S & C'S

3°
9
8

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Date 8/9/89

Project No. E-25-M42 Center No. R6467-0A0

Project Director G. G. Eichholz School/Lab ME

Sponsor Oak Ridge National Lab/ Martin Marietta Energy Systems, Inc.

SC no.
Contract/Grant No. 19X-SB729C GTRC XX GIT ___

Prime Contract No. DE-AC05-840R21400

Title Dose-Rate Dependence of Thermoluminescent Dosimeters/DE-AC05-84021400

Effective Completion Date 6/30/89 (Performance) 6/30/89 (Reports)

Closeout Actions Required:

___ None
X Final Invoice or Copy of Last Invoice
X Final Report of Inventions and/or Subcontracts -Questionnaire sent to P/I
X Government Property Inventory & Related Certificate
___ Classified Material Certificate
X Release and Assignment
___ Other ___

Includes Subproject No(s). ___

Subproject Under Main Project No. ___

Continues Project No. ___ Continued by Project No. ___

Distribution:

X Project Director
X Administrative Network
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___ Research Security Services
X Reports Coordinator (OCA)
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X Project File
2 Contract Support Division (OCA)
___ Other ___

E-25-M42

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April 15, 1988

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ATLANTA, GEORGIA 30332 U.S.A

Dr. James S. Bogard
Environmental & Occupational Safety Div.
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37831

Monthly Progress Report - Our Project E25-M42

Dear Dr. Bogard:

The contractual arrangements for this project, concerning the measurement of the dose rate dependence of TLD's, were finally completed in mid March. We are now in the process of constructing a frame work to support the TLD's during irradiation in a rigid, reproducible geometry. Miss Susan Durrence and Mr. Won-jae Park are engaged in this work.

A 200 μCi cesium-137 has been selected and is being sent to Du Pont - NeN Products for recalibration to provide an NBS-traceable updated calibration. An ion chamber instrument has also been calibrated internally and will be used to monitor the field on a regular basis.

We expect to be ready to receive the TLD's by the end of the month.

Please call me at (404) 894-3722 if you have any questions.

Yours sincerely,

G. G. Eichholz
Regents' Professor

GGE/jr

cc: P. Heitmuller (OCA)

E-25-M42

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May 18, 1988

Dr. James S. Bogard
Environmental and Occupational Safety Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37831

Monthly Progress Report - Our Project E25-M42

Dear Dr. Bogard:

During the past weeks work has concentrated on designing and building an irradiation facility for this work. A relatively isolated room on the top floor of the Old Civil Engineering Building has been selected. A framework of slotted angle iron has been set up and a number of 1/2 inch Lucite panels has been cut and shaped to curve to support the TLD's. They are being mounted at present.

The cesium-137 source has been sent out for recalibration and is expected back any time now.

A tentative exposure schedule has been drawn up and we need to get together with you on the transport arrangements and a suitable readout schedule.

A preliminary abstract on this work has been submitted for the DOE Model Conference this fall.

Yours truly,

G. G. Eichholz

G. G. Eichholz
Regents' Professor

GGE/bc
cc: P. Heitmuller (OCA)

E-25-M42

#3

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June 9, 1988

Dr. James S. Bogard
Environmental and Occupational Safety Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37831

file

Monthly Progress Report - Our Project E25-M42

Dear Dr. Bogard:

Since our last report, the irradiation frame work has been completed and installed. The recalibrated cesium-137 source has been received back and we are in the process of cross calibrating our dosimeters using ion chambers and TLD's and verifying the dose rates at the various exposure positions.

We are basically ready to receive your TLD's and need to work out shipping arrangements and an exposure schedule with Tony Rhea.

I will be away the next few weeks and suggest that these arrangements are worked out with Susan Durrence or Won-jae Park as soon as possible. They can be reached at (404)894-3375.

Yours truly,

G. G. Eichholz
Regents' Professor

GGE/bc
cc: P. Heitmuller (OCA)
R. F. Dawkins (ME)

E-25-M42

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July 15, 1988

Dr. James S. Bogard,
Environmental and Occupational Safety Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831

Monthly Progress Report - Our Project E25-M42

Dear Dr. Bogard,

The irradiation assembly was completed and the past few weeks have been used to measure dose rates around the mounted source. Using a graphite ionization chamber and a series of TLD-100, the dose measurements were taken at various distances from the source. The results showed serious discrepancies between calculated and measured doses and the dose measurements themselves and work is in progress to clarify the situation.

As soon as the measurements appear satisfactory, we will make arrangements to expose your TLD's.

Yours sincerely,

G. Eichholz

Geoffrey G. Eichholz
Regents Professor

cc: P. Heitmuller (OCA)
R. F. Dawkins (ME)

Telephone: 404-894-3720 Telex: 542507 GTRIOCAATL Fax: 404-894-3120 (Verify: 404-894-6951)

8-25-M42

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August 18, 1988

Dr. James S. Bogard
Division of Environmental & Health Protection
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831

Monthly Progress Report - Our Project E25-M42

Dear Dr. Bogard,

During the past month we have worked to resolve apparent discrepancies between calculated and measured dose rates around our cesium-137 source. A series of LiF TLD's have been recalibrated in our cobalt calibration facility and we have intercompared readings at a variety of distances. Uncertainties still seem excessively high at low dose rates and we are working to improve that situation.

Basically we feel we are ready to receive your TLD's for exposure. Following our phone conversation in which you indicated that you had an insufficient number of Panasonic 802AS TLD's available for this work, I was able to obtain 100 of these TLD's on loan from Georgia Power Co. Central Analytical Laboratory through the courtesy of Mr. Donald Philpotts. I will bring these TLD's to your lab for amealing and processing during my visit to your division on August 19. At that time I hope we can decide on logistical aspects of the TLD exposures.

Yours sincerely,

Geoffrey G. Eichholz
Regent's Professor

GGE/lg

cc: P. Heitmuller (OCA)
R.F. Dawkins (ME)

E-25-M42

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September 14, 1988

Dr. James S. Bogard
Division of Environmental & Health Protection
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831

Monthly Progress Report - Our Project E25-M42

Dear Dr. Bogard,

Following our visit to ORNL on August 19, we have finalized the exposure schedule and have developed a documentation format.

The first ORNL badges to be exposed are being shipped to you at present for reading. We have just received the 100 Panasonic badges from you and they are being readied for exposure.

We are continuing our confirmatory dose measurements to establish more precise dose rate values.

We have also requested a no-cost extension of the contract to permit completion of the work on the low-dose-rate exposures.

Yours sincerely,

Geoffrey G. Eichholz
Regents Professor

GGE/lg

cc: P. Heitmuller (OCA)
R.F. Dawkins (ME)

E-25-M42

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November 14, 1988

Dr. James S. Bogard
Division of Environmental & Health Protection
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831

<u>Monthly Progress Report - Our Project E25-M42</u>

Dear Dr. Bogard:

Routine exposure of TLD's is progressing smoothly and we have received back data on two batches of X-10 TLD's. We hope to receive the readings on the Panasonic badges fairly soon to permit timely evaluation and we need to receive some recycled TLD's to continue exposure in those cases, where additional data seem desirable. Because the rounding off of glow curve readings introduces excessive errors we still have to recalculate the raw data to look for dose rate effects, if they exist.

It is evident that these additional measurements and the ongoing long-term exposures cannot be completed by December 13, 1988, the current contract termination date, and we would like to see a small increment in the contract to take it into March 1989. Please call me if you have any questions.

Yours sincerely,

G. Eichholz

Geoffrey G. Eichholz
Regents' Professor

GGE:cv

cc: P. Heitmuller (OCA)
R. F. Dawkins (ME)

E-25-M42

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June 23, 1989

Dr. James S. Bogard
Division of Environmental and
Health Protection
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831

Final Report - Our Project E25-M42

Dear Dr. Bogard:

We are sending you herewith one copy of the draft final report on the above project, "Dose Rate Dependence of Thermoluminescent Dosimeters". We would appreciate it if you and Tony Rhea, if he is still available, would review this report and let us have your comments as soon as possible. The figures in the report are not in final form and we intend to redraw them for better quality in the meantime.

We believe the results are interesting and appear to provide some evidence of dose rate effects. We have enjoyed working with you on this project and I hope there will be joint ORNL/Georgia Tech health physics projects in the future.

I am sending a separate copy to Tony Rhea directly.

With best regards.

Yours truly,

G. G. Eichholz
Regents' Professor Emeritus

GGE/bc
cc: Dr. B. Kahn
Mr. R. F. Dawkins

DOSE RATE DEPENDENCE OF THERMOLUMINESCENT DOSIMETERS

Final Report

Subcontract No. 19X-SB729C
Our Project E25-M42
As Amended

submitted by

Geoffrey G. Eichholz
Principal Investigator

to

Oak Ridge National Laboratory
Martin Marietta Energy Systems, Inc.
P.O. Box M
Oak Ridge, TN 37831

Nuclear Engineering and Health Physics Programs
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332

May 1989

ABSTRACT

A large set of Harshaw TLD-700 and Panasonic AS802 thermoluminescent dosimeters have been exposed to a cesium-137 gamma source to compare sensitivity, precision and response rates and to determine any dose-rate dependence. Dose rates varied from 10 - 200 μR/hr and cumulative doses from 0 - 800 mR (0-8mGy). Under the conditions of exposure, the Harshaw badges read consistently higher than the calculated dose values, whereas the Panasonic badges read close to, or somewhat lower than the expected dose.

An apparent dose-rate effect was observed for the Harshaw badges on the long-term fading that was most pronounced at the lowest dose rates. A different, less-clearly dose-rate dependent effect was seen for the Panasonic badges, where a trend reversal occurred with exposure time. In practice, such fading effects as observed can be corrected by incorporating an appropriate algorithm into the evaluation process.

PROJECT PERSONNEL

(All part-time)

Geoffrey G. Eichholz, Ph.D.	Principal Investigator
Scott G. Dyer, B.S.	Graduate Research Assistant
Won-jae Park, M.S.	Graduate Research Assistant
Susan E. Durrence, B.S.	Graduate Research Assistant
Sandra S. Dalton, B.S.	Graduate Research Assistant

ACKNOWLEDGEMENTS

This project was conducted in close cooperation with Mr. Tony A. Rhea of ORNL, who suggested the problem and reviewed the final report. The work was greatly facilitated by a timely loan of 100 Panasonic TLD's from Mr. Donald K. Philpotts of Georgia Power Company's Central Analytical Laboratory.

INTRODUCTION

Thermoluminescent dosimeters (TLD) have generally replaced other devices as personal dosimeters. Their advantages include light weight, moderate cost, good sensitivity over a wide range of photon energy, adequate linearity with dose and reusability. They lend themselves to automated handling for reading dose values and can be handled relatively easily in large numbers. Depending on the type of TLD used, early fading may be a problem, and there is enough variability among TLD chips to require individual calibration and tracking for each dosimeter. Typically the TLD's, in chip form, are housed in square or round plastic capsules, two or four per capsule, with different absorber foils, or none, to provide discrimination for recording beta, gamma or neutron exposure. Usually TLD badges are worn at lapel or belt level, but incorporation into security badges is also common, as are special exposure settings in head bands or finger rings, especially in medical situations. As a result, electron equilibrium at the TLD may not always be complete and, ideally, any phantom calibration of the dosimeters should allow for such variations.

The present project arose from a change-over in the TLD's used for personnel monitoring at two facilities operated by Martin Marietta at Oak Ridge, TN from Harshaw LiF dosimeters, type TLD 700, mounted in Teflon holders, ("blue badges") to Panasonic $Li_2B_4O_7$:Cu TLD's, Type AS-802 mounted in a type UD885 hanger, a plastic holder designed for easy handling in an automatic reader. Some questions had been raised regarding the relative sensitivity of these dosimeters, their precision and any possible dose-rate effect. Adequate numbers of each type of TLD's had to be tested under highly reproducible conditions and read under conditions representative of normal practice, while covering a range of doses and dose rates.

An NBS-traceable Cs-137 source was used in all tests in a fixed configuration and blank TLD's were reserved for background checks and transit dosimeters. All dosimeters were exposed normally to the face of the TLD holder, to avoid directionality problems,(e.g. 1). Most of the exposures times were fairly long; as a result short-term fading was not expected to be a major problem (2), though reading delays from the end of exposure to the actual time of readings at ORNL varied from 3- 10 days and may have introduced an additional source of uncertainty.

However, the time between annealing of the TLD's and the start of radiation exposure varied to some extent, partly on account of differences in the equipment used between the two facilities involved, partly because of variations in shipping time. Thus, the Harshaw devices probably had 1 - 2 weeks of sensitivity fading before being shipped.

Both sensitivity fading and signal fading are well-known phenomena and the purpose of the present tests was to establish the magnitude of such effects. In practice, the fading is corrected for in the evaluation of the TLD reader output data by applying an appropriate algorithm. However, that procedure assumes a constant correction factor and independence from dose rate.

EXPERIMENTAL PROCEDURE

The two types of TLD, Harshaw TLD-700 ("blue") and Panasonic AS-809, were exposed to Cs-137 photons of 662 keV energy on the Georgia Tech campus in Atlanta, GA. The TLD's were pre-annealed at Oak Ridge National Laboratory (ORNL), shipped to Georgia Tech, exposed there for varying periods and then returned to ORNL for reading. Batches of exposed TLD's were shipped by Federal Express in lead-lined pouches, of a type used to shield exposed film from airport baggage inspection units (U.S. Mail was considered too variable in time). Each batch included a transit monitor and background ("blank") TLD's. One hundred Panasonic TLD's were obtained on loan from the Georgia Power Company's Central Analytical Laboratory to supplement the number of TLD's available for this test.

Exposures were performed in a room on the top floor of the Old Civil Engineering Building, Room 307A, which was cleared for this purpose. The room is air conditioned and temperature was monitored to allow for unexpected variations (3). As the air conditioner tended to freeze up, care had to be taken to check this daily, as otherwise room temperature would rise unacceptably. The building is of brick construction and has a relatively low radium/radon level (4) which, however, was not determined in that particular room.

The exposure array consisted of a thin wooden table top mounted on slotted angle supports, 30 in. (90 cm) above the floor. At selected distances, curved sheets of 1/2 inch (1.25 cm) clear Almac AP acrylic plastic, 20 x 50 cm, were mounted by attachment to slotted upright metal supports. The plastic sheets were molded to fit the needed curvature by heating the acrylic to 200°C for 30 minutes and clamping it to a curved wood templet while hot. The support plastics were mounted at 54, 76, 106, 168 and 239 cm from the source axis to give the calculated dose rates for the source employed. The TLD's were mounted in horizontal rows, away from the supports, between two curved plastic sheets to simulate near-equilibrium. Fig. 1 is a plan of the exposure array. Each position would hold 3 groups of any time.

An exposure plan was prepared to establish a reasonable time schedule while still covering the necessary ranges in cumulative dose and dose rates. At the lowest dose rates, background was found to constitute a significant part of the recorded doses.

The source employed was a cesium-137 source, model NES-356 supplied by New England Nuclear Corp., now DuPont NEN Products, as a Vial Type E Reference Source. In such sources, the source material, CsCl, is uniformly dispersed in 20 cc of epoxy cast resin inside a low-density polyethylene vial. The source was returned to the supplier for recalibration. Its source strength was certified as 6.4 MBq (0.174mCi) as of May 11, 1988 with an overall error of ± 2.6%. The relative intensity is quoted in the Certificate of Calibration as 85.1% 661.7 keV, 2.0% 31.8 keV, 3.7% 32.2 keV and 1.34% 36.4 keV (4).

Background TLD's were placed on a shelf in an adjoining room (307) about 21 ft. (7m) from the cesium source. The transit monitors were stored in a lead shield until needed.

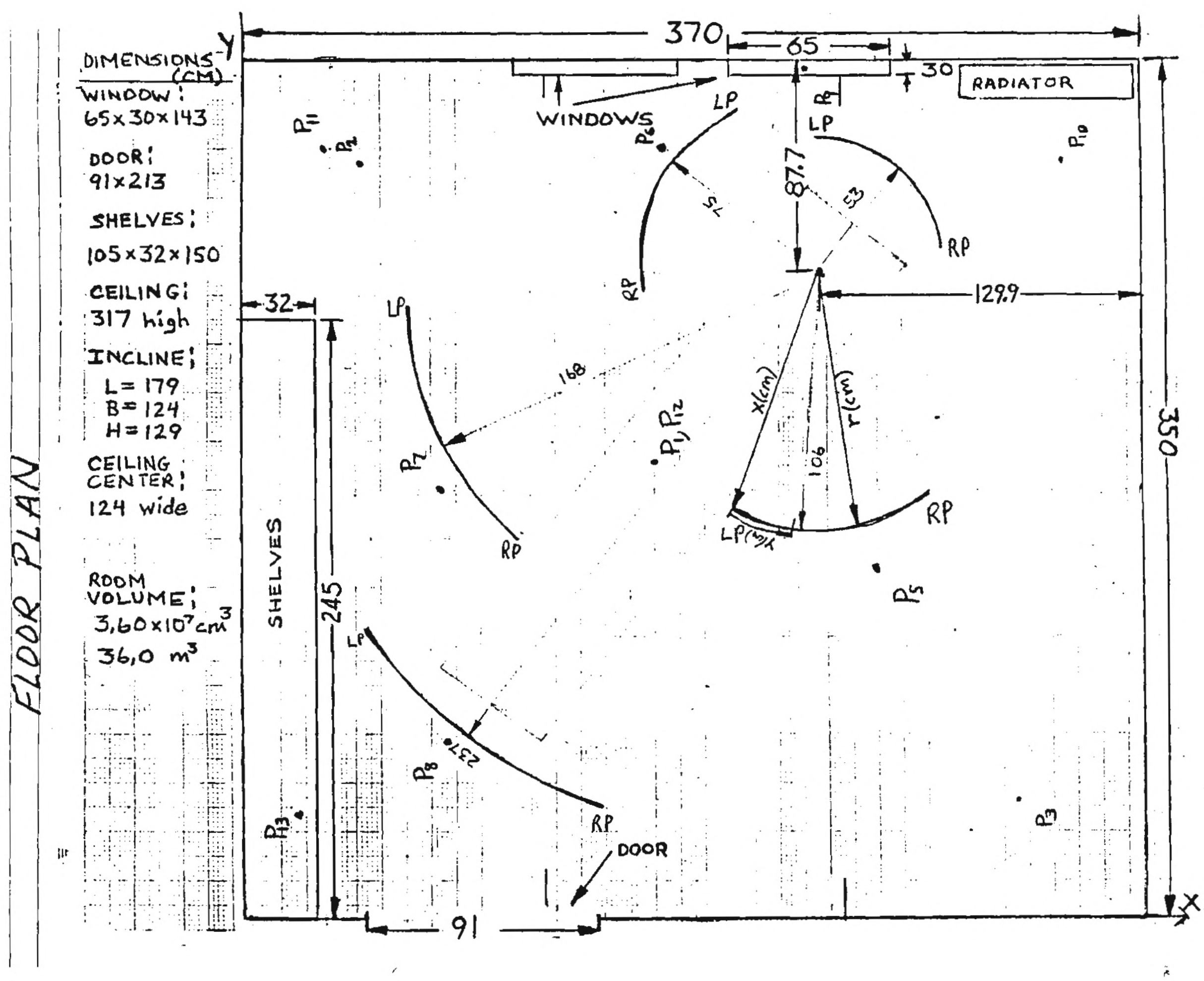


Fig. 1 Plan of Exposure Set-up

On completion of the exposure the TLD's were read at ORNL and the readings were reported back to Georgia Tech. Initial reports consisted of data evaluated by the reader program, which corrected for fading and rounded off to the nearest 5 mrem value. This obscured the effect that was investigated and all later tests used the "raw", uncorrected reader output data.

PRELIMINARY MEASUREMENTS

Exposure-rate Determinations

To verify the calculated dose rates at the exposure positions, independent dose measurements were done using both LiF (Harshaw TLD100) and CaF_2:Dy (Harshaw TLD 200) dosimeters. These TLD's were calibrated using a cobalt-60 source system ("Crenshaw's Mountain") at Georgia Tech, which is routinely used by Georgia Power Co. to calibrate their TLD's and whose dose distribution is well established. For 10 TLD's of each type, calibration factors were 9.02 ± 0.45 mrad/nC for TLD-100 and 0.51 mrad/nC for TLD-200. Twenty nine TLD-200 were used to map out the exposure array in Room 307A. Table 1 lists the data obtained from these tests. Note, that the measured exposure rates include background, whereas the calculated values do not. From these results the following exposure rates were derived for purposes of planning the exposure schedule (Table 2). A Victoreen air ionization chamber was used to verify the radiation field at selected positions.

TABLE 2
ABSORBED DOSE RATES AT EXPOSURE POSITIONS

Distance (cm) From Source	Absorbed Rate (μrad/hr)
54	201 ± 5
76	105 ± 11
106	54 ± 9
168	25 ± 1
239	13 ± 1

TABLE 1

TLD Label	Radial Distance (cm)	Location x (cm)	y	Measured Exposure Rate mrad/d	μR/hr	Calculated Exposure Rate mrad/d
A	55.0	54.0	13.0	4.65	194	4.53
B	55.0	54.0	15.5	4.78	199	4.53
C	56.0	54.0	33.0	4.91	205	4.37
D	56.0	54.0	36.0	4.85	202	4.37
E	56.0	54.0	54.0	4.92	205	4.37
F	77.5	75.3	61.5	2.31	96	2.28
G	77.5	75.3	64.0	2.66	111	2.28
H	76.0	75.3	21.0	2.58	108	2.37
I	76.0	75.3	24.0	2.82	118	2.37
J	77.2	75.3	92.0	2.18	91	2.30
K	106.5	104.0	12.5	1.50	63	1.21
L	105.5	104.0	9.5	1.54	64	1.23
M	113.0	104.0	42.0	1.17	49	1.07
N	112.5	104.0	39.5	1.15	48	1.08
O	118.0	104.0	81.0	1.05	44	0.98
P	175.0	168.0	69.0	0.57	24	0.45
Q	175.0	168.0	66.0	0.60	25	0.45
R	169.0	168.0	11.0	0.64	27	0.48
S	169.0	168.0	8.5	0.58	24	0.48
T	174.0	168.0	39.0	0.60	25	0.45
U	238.0	238.5	29.0	0.28	12	0.24
V	238.0	238.5	32.0	0.37	15	0.24
W	238.0	238.5	64.0	0.32	13	0.24
X	238.0	238.5	67.0	0.28	12	0.24
Y	238.0	238.5	25.0	0.32	13	0.24

Backscatter Check

Because of the relatively small size of the room, there was concern that there might be backscatter effects contributing to the exposure of TLD's on the "wings" as against those close to the array centerline. Three TLD's were placed at heights of 25, 62, and 97 cm from the wall, all at a distance of 100 cm from the source and exposed for 4 days. Table 3 shows the results obtained.

TABLE 3

BACKSCATTER TEST

Height (cm)	Gross Dose (mrad)	Background Dose (mrad)	Net Dose (mrad)	Ratio
25.0	8.53 ± 0.2	1.8 ± 0.13	6.73 ± 0.51	1.00
62.0	7.38 ± 0.44		5.58 ± 0.52	0.83 ± 0.1
97.0	9.16 ± 0.55		7.36 ± 0.69	1.1 ± .13

As can be seen from the data, no backscattering trend was established.

Fading Characteristics of TLD-200's

The TLD's also needed to be checked for fading properties. A total of six TLD's were placed in the configuration described immediately above. Two TLD's were removed every 24 hours and read immediately. The height of the 6 TLD's was 100 cm from the floor. Table 4 lists the results obtained.

TABLE 4

FADING TEST

Time (days)	Gross Dose (mrad)	Background Dose (mrad)	Net Dose (mrad)	Ratio
1.0	3.68 ± 0.18	1.8 ± 0.13	1.88 ± 0.16	1.0
2.0	5.19 ± 0.31		3.39 ± 0.32	1.8 ± 0.23
3.0	6.52 ± 0.52		4.72 ± 0.51	2.5 ± 0.35
4.0	9.16 ± 0.55		7.36 ± 0.69	3.9 ± 0.50

According to the data obtained no noticeable fading effect could be demonstrated at this low dose range.

Background Measurements

At the low dose rates involved in some of the exposures, background becomes a significant fraction of the measured dose. Background levels both inside the room and outside it were measured with TLD-200 and Victoreen ionization chambers. The ionization chambers had been calibrated within 6 months of measurement by the Georgia Tech Radiological Safety Office. The chambers were placed near the center of the room at points P1, P2, and P3, indicated in Figure 1, and exposed for 1 - 6 hours. The results are shown in Table 5. The average background dose rate from all measurements was 0.019 ± 0.004 mrad/hr (4.56μGy/d), corrected for temperature and pressure.

TABLE 5

BACKGROUND MEASUREMENTS

Chamber - Positions	Distance To Walls (cm)	Exposure Time (hr)	Measured Dose (mrad)	Dose Rate (mr/hr)	Normalized* Point (cm)
A P1	191,164rr	1.0	0.024	0.024	179,186
B P1	191,164rr	1.0	0.021	0.021	50,300
C P1	191,164rr	1.0	0.021	0.021	320,50
B P2	50,50 rl	2.0	0.044	0.022	284.5,315
B P1	191,164rr	2.0	0.038	0.019	243,140
C P1	191,164rr	2.0	0.035	0.018	178,314
C P3	50,50 fr	4.0	0.062	0.016	79,176
B P1	191,164rr	4.0	0.061	0.015	87,71
C P1	191,164rr	4.0	0.061	0.015	34,-17
A P1	191,164rr	6.0	0.088	0.015	339,311
C P1	191,164rr	6.0	0.098	0.016	35,313
					179,186

P average (191,164) = 0.019 mrad/hr, assuming this point is the center of the room

A P4	85,35 rr	8.0	0.126	0.016	22.44
C P5	107,140fr	8.0	0.116	0.015	
C P6	178,35 rl	8.0	0.120	0.015	
B P7	79,174rl	8.0	0.142	0.018	
B P8	87,71 fl	8.0	0.117	0.015	
BwP9	34,-17 rr	8.0	0.132	0.017	
A P10	31,39 rr	8.0	0.132	0.017	
A P11	35,36 rl	8.0	0.152	0.019	
C P12	191,164rr	8.0	0.114	0.014	
A P13	22,44 fl	8.0	0.118	0.015	

P average (room) = 0.016 mrad/hr.

* The locations are first given from the point P to the nearest two walls.
RR - near right RL - rear left FR - front right FL - front left
The locations are then normalized to the front left corner of the room.
The points are on the floor plan in Figure 1.

A separate test was performed with the ion chambers placed at various points around the room, closer to the walls, for 8 hour periods. These results averaged to a lower value, as shown in the second part of Table 5, of 0.016 mrad/hr. This lower value is ascribed partly to shadow shielding by the walls, partly to charge leakage from the chambers which was determined separately to average to 9 μR/hr equivalent. This became particularly noticeable in tests run over yet longer periods, 13 - 19 hr. over night.

Additional tests were done to measured background rates throughout the building. These results are shown in Table 6. Their principal import is to shown an evident decrease in background on the higher floors.

TABLE 6

BACKGROUND IN OLD CE BUILDING

FLOOR	DOSE RATE mrad/hr (at door)	DOSE RATE mrad/hr (mid hall)	DOSE RATE mrad/hr (down hall)
1	0.020	0.019	0.023
2	0.019	0.019	0.022
3	0.019	0.015	0.018
avg.	0.019 ± 0.0006	0.018 ± 0.0023	0.021 ± 0.0026

TEST RESULTS

Preliminary Measurements

As mentioned, all the TLD's were sent to ORNL for reading. The reading data were then analyzed on receipt from ORNL. The first readings were rounded off in compliance with Laboratory procedure; however, that introduced larger errors than the dose-rate effects that were looked for. Consequently, all results were subsequently analyzed on the basis of the "raw" TLD reader outputs.

Reporting forms identified badges by type and number. Type A referred to the Panasonic badges, Type B to the "blue" Harshaw badges. Because the blue badges have two pairs of chips each, one of which is shielded with an $A\ell$ foil, two dose values were reported typically, D and D', where D' is the "shielded" reading.

Table 7 shows the quality of the data received for the first round of badges. Note the effect of rounding on the reported D' values as against the "raw" D values. The ratios of predicted dose vs. measured dose were plotted against total dose, with or without correction for background. Fig. 2 shows the uncorrected distribution, which shows the importance of the background correction at low total doses. It also seemed to show that the ORNL readings consistently were higher by about 10% than the doses "calculated"; this discrepancy probably arose from the assumption of 100% emission intensity in calculating the exposure rate, whereas the calibration certificate clearly specified an 85% intensity for the 662 keV photon or 92% total photon output per decay.

TABLE 7

Analysis of First Batch (Type B)

Label	Distance (cm)	Pred. D (mrad)	Rept. D' (mrad)	Rept. D (mrad)	R_1	R_2
A1	54	186	170	192.4	1.09	1.12
A2	54	186	170	191.5	1.09	1.13
A3	54	186	190	203.2	0.98	1.05
A4	54	186	160	187.9	1.16	1.15
B4	54	101.2	80	90.55	1.27	1.18
B5	54	101.2	90	93.18	1.12	1.14
B6	54	101.2	90	93.19	1.12	1.14
D1	76	100	100	110.05	1.0	1.20
D2	76	100	110	116.07	0.91	1.11
D4	76	100	100	106.67	1.0	1.25
D5	76	52.9	40	50.28	1.32	1.16
D6	76	52.9	50	59.99	1.06	0.95
D7	76	52.9	50	57.11	1.06	0.95
E1	76	100	100	109.12	1.0	1.21
E2	76	100	100	116.35	1.0	1.12
E4	76	100	90	102.32	1.11	1.32
F6	76	97.2	110	114.85	0.88	1.10
F7	76	97.2	100	116.36	0.97	1.08
F8	76	97.2	90	95.85	1.08	1.41
F9	76	97.2	100	121.11	0.97	1.03
G1	106	27.2	30	40.89	0.91	0.75
G2	106	27.2	30	31.44	0.91	1.01
G3	106	27.2	30	35.69	0.91	0.87
G4	106	50	50	59.18	1.0	1.54
G5	106	50	60	66.39	0.83	1.26
G6	106	50	60	62.50	0.83	1.40
I1	106	50	60	67.90	0.83	1.21
I2	106	50	50	64.69	1.0	1.32
I3	106	50	70	80.77	0.71	0.92
J4	168	20	40	40.60	0.5	1.44
J5	168	20	30	27.90	0.67	1.65
J6	168	20	30	33.69	0.67	2.86
J7	168	20	30	29.78	0.67	6.47
K1	168	12.6	0	22.12	----	----
K2	168	12.6	0	13.80	----	----
K4	168	12.6	20	19.8	0.63	0.82
P1	239	10.0	20	24.17	0.5	3.97
P2	239	10	20	20.92	0.5	1.73
P3	239	10	20	24.22	0.5	4.05
U1	239	6.6	0	10.85	----	----
U2	239	6.6	0	18.48	----	----
U3	239	6.6	0	16.00	----	----

$R_1 = \dfrac{\text{Predicted Dose}}{\text{Reported Dose}'}$ $R_2 = \dfrac{\text{Predicted Dose}}{\text{Reported Raw Dose - Background}}$

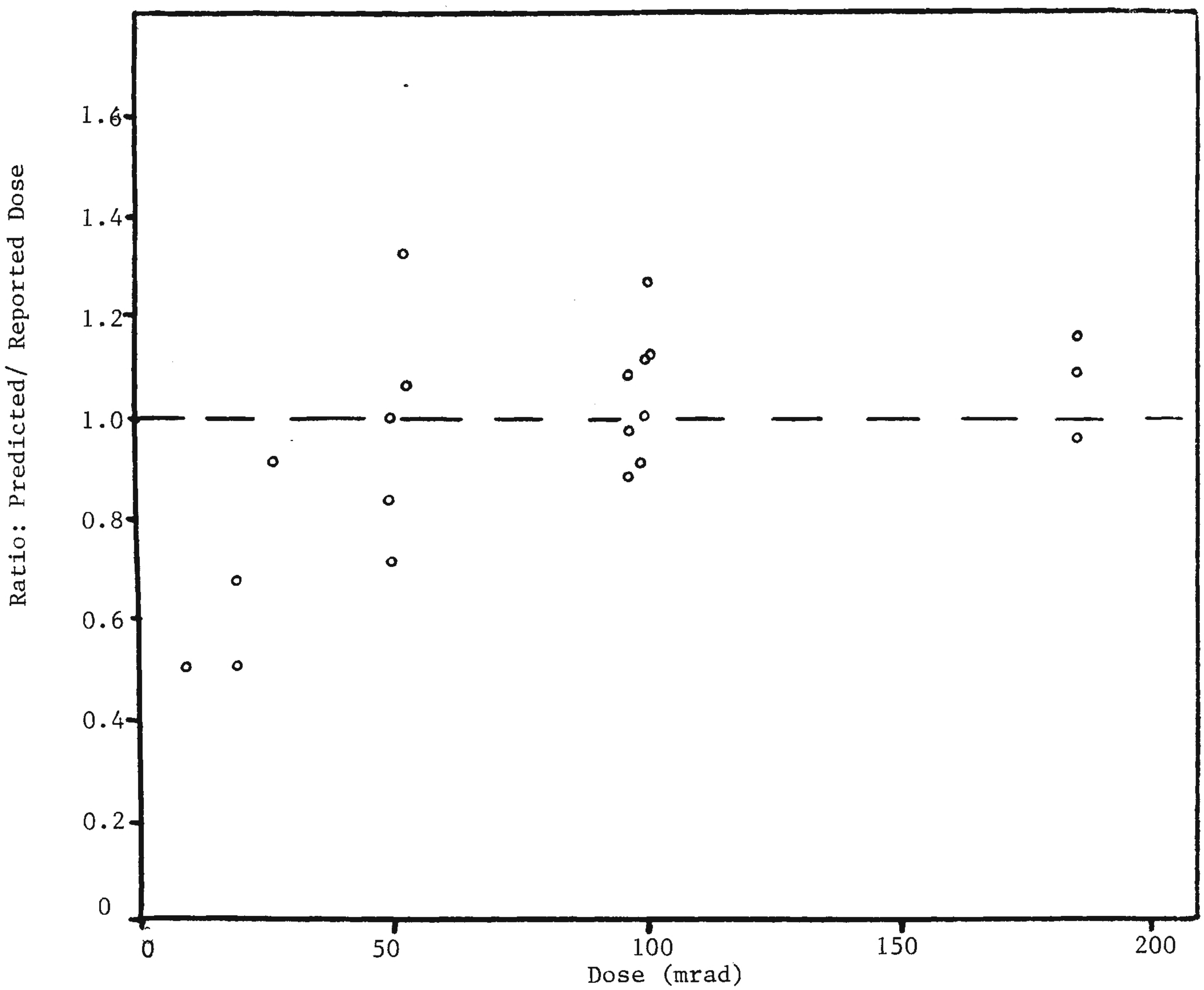


Fig. 2: Type B Badge Performance Without

Background Correction

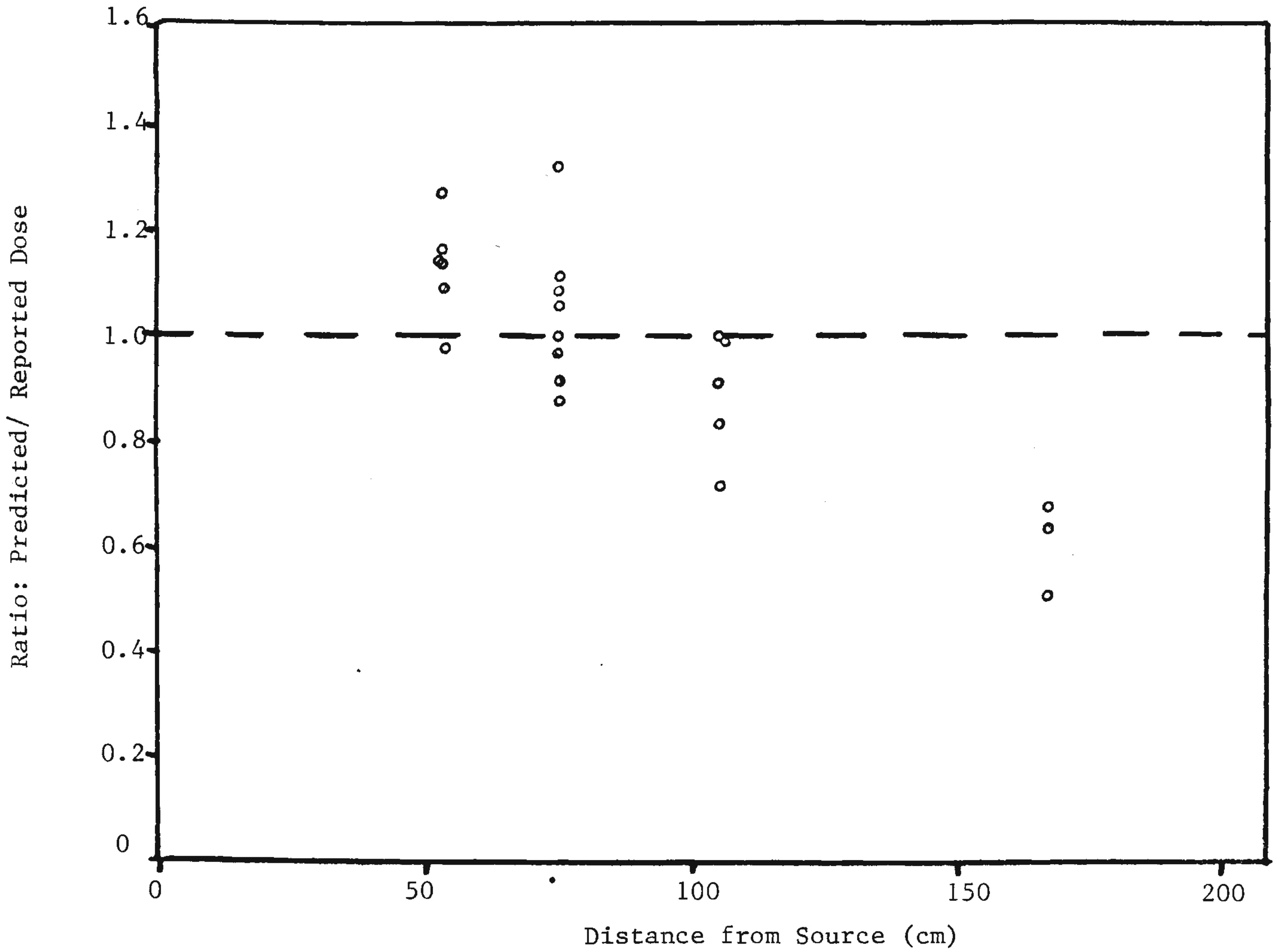


Fig. 3: Dose Rate Effect for Preliminary Test Readings

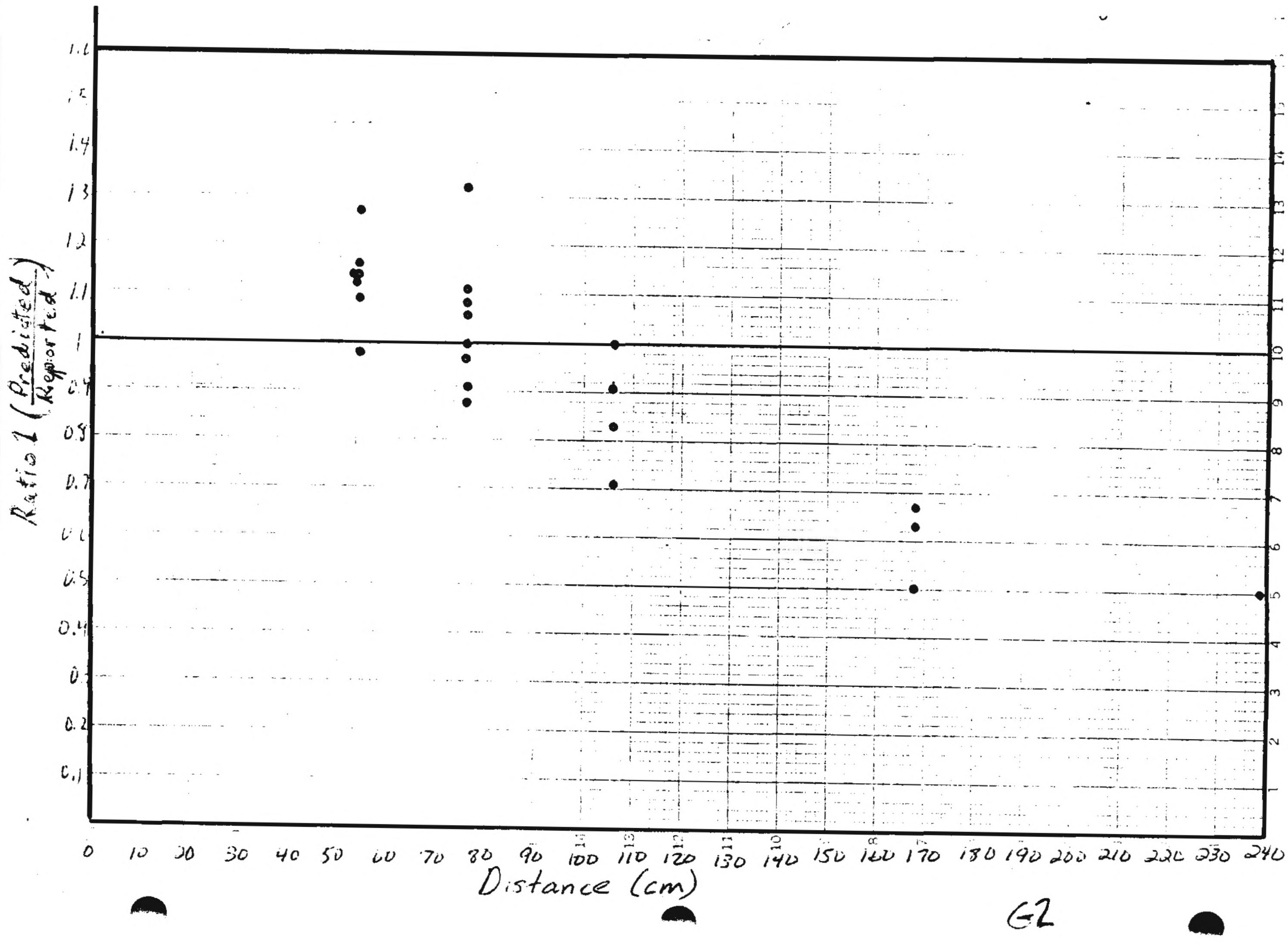


Fig. 3: Dose Rate Effect for Preliminary Test Readings

TABLE 8

Calculations for Expected Dose Rate and Dose for Type A Badges, UD-802 dosimeters in UD-874 holders.

Location Distance (cm)	Radial Distance (cm)	Activity (μCi)	Expected Dose Rate (μR/hr)	Time (hr)	Expected Dose (mR)
53	55.1	173	188.0	497.5	103.0
	54.9	170.3	186.5	504	104.6
	55.6	172.8	184.4	957	193.3
	55.6	171.9	183.8	3976	795.9
75	76.6	173	97.30	484.3	56.38
	74.9	170.3	100.2	504	60.08
	76.1	172.8	98.44	957	110.0
	75.6	171.9	99.24	3976	458.2
106	103.3	170.3	52.67	504	36.12
	104.6	172.8	52.10	957	66.69
	104.9	172.4	51.69	2062	141.1
	103.6	171.9	52.83	3976	275.2
168	166.9	170.3	20.18	504	19.75
	166.9	172.6	20.45	812	33.43
	166.9	172.4	20.42	2062	76.61
	170.4	171.9	19.53	3976	142.8
237	237.4	172.6	10.11	769	24.60
	236.9	172.4	10.14	1680	51.54
	236.9	171.9	10.11	3976	105.3

TABLE 9

Calculations for Expected Dose Rate and Dose for Type B Badges, TLD-700 dosimeters.

Location Distance (cm)	Radial Distance (cm)	Activity (μCi)	Expected Dose Rate (μR/hr)	Time (hr)	Expected Dose (mR)
53	55.4	172.8	185.8	504	103.3
	55.4	172.7	185.7	926	190.1
	55.4	172.6	185.6	1493	318.9
	54.7	171.1	188.7	2111	433.4
	55.4	172.4	185.4	2135	437.5
	55.4	172.0	184.9	3975	799.9
75	75.9	172.8	99.25	504	59.71
	74.6	172.7	102.4	926	113.0
	76.3	172.7	97.89	952	113.5
	74.8	171.1	100.9	2111	248.1
	76.6	172.0	96.74	3759	428.6
	74.6	171.8	101.9	4529	535.3
106	104.4	172.8	52.32	504	36.05
	104.2	172.7	52.49	926	66.77
	104.7	171.1	51.51	2111	143.8
	104.0	172.4	52.65	2135	154.0
	104.0	172.0	52.53	3759	262.4
168	169.4	172.8	19.87	504	19.70
	167.4	172.7	20.34	797	34.37
	168.4	171.1	19.91	2111	77.14
	168.4	172.4	20.06	2135	84.46
	167.4	172.0	20.25	3975	145.4
237	236.9	172.8	10.16	504	14.80
	236.9	172.7	10.15	769	25.98
	236.9	172.5	10.14	1679	58.66
	236.7	171.1	10.08	2111	56.38
	237.4	172.0	10.07	3759	102.8

The following tables summarize the results obtained. Each dose value listed is the average of several TLD's and the number in parenthesis indicates the number of units in each case. Tables 10 - 14 contain data for Type A, Panasonic AS-802 badges, Tables 15-16 for the TLD-700 badges. Subsequent graphs depict trends for elements 1 - 4 separately, and for 2 and 3 together for Type A badges, and comparable trends for positions 1 and 2 for Type B.

Parameters for Tables 10 - 16.

Location Distance = General distance from source to acrylic boards supporting badges.

Radial Distance (R) = Distance from source to the center point of the group of badges at that location for a specific exposure time.

Activity = Average activity of cesium-137 source during that particular exposure time, where A_o = 174 μCi on 5/11/88.

$$A = 1/2\, A_o\, [\exp(-\ln 2/t_{1/2} \times t_1) + \exp(-\ln 2/t_{1/2} \times t_2)]$$

$$= 87\ \mu\text{Ci}\, [\exp(-6.3 \times 10^{-5} t_1) + \exp(-6.3 \times 10^{-5} t_2)]$$

Expected Dose Rate = Dose rate calculated by:

$$D = \frac{\Gamma A}{d^2} = \frac{3.3 \times 10^3\ R\ (\text{cm}^2/\text{hr}\ \mu\text{Ci}) \times A\ (\mu\text{Ci})}{R^2 (\text{cm}^2)}$$

Time = Exposure time period for that particular set of badges at that location.

Expected Dose = [(Expected Dose Rate from Exposure) + (Dose Rate from Background) + (Dose Rate from Transit)] x Exposure Time.

Total Dose Measured = Average of dose measured at that distance for that exposure time, standard deviation is,

$$\sigma = \sqrt{\frac{\sum_{i=1} (x_i - \bar{x})}{n - 1}}$$

where x_i = Reading from one element in one dosimeter.
$\bar{x}$ = Average readings for one element in set of dosimeters.

Net Dose Rate = [(Total dose measured) - (Background dose measured)] /Exposure time.

Ratio of Doses = Gross Expected dose/Measured dose.

TABLE 10

Exposure of Type A Badges, UD-802 Dosimeters: Data for Element 1, $CaSO_4$, with 28 mg/cm^2 Mylar Filtration

Location Distance* (cm)		Exposure Time (hr)	Total Dose Measured (mR)	Net Dose Rate Measured ($\mu R/hr$)	Ratio of Total Doses (Exp/Mea)
53	(7)	497.5	110.2+/-9.6	184.7	0.9347
	(3)	504	120.3+/-2.1	203.6	0.8695
	(6)	957	194.0+/-16.3	173.0	0.9964
	(7)	3976	745.1+/-48.6	168.8	1.068
75	(6)	484.3	64.43+/-2.54	100.0	0.8751
	(3)	504	71.77+/-3.88	107.3	0.8371
	(7)	957	110.2+/-9.1	85.48	0.9982
	(6)	3976	443.7+/-32.2	92.98	1.034
106	(3)	504	48.17+/-6.59	60.46	0.7498
	(6)	957	70.60+/-4.03	44.10	0.9446
	(6)	2062	142.2+/-15.3	43.84	0.9923
	(6)	3976	260.5+/-20.4	46.91	1.056
168	(3)	504	25.90+/-2.46	16.27	0.7625
	(8)	812	40.78+/-2.64	15.25	0.8198
	(6)	2062	79.22+/-3.75	13.30	0.9671
	(2)	3976	153.0+/-11.3	19.87	0.9333
237	(6)	769	33.58+/-5.32	6.736	0.7326
	(3)	1680	64.20+/-8.30	7.381	0.8028
	(6)	3976	121.3+/-3.60	11.90	0.8681

TABLE 11

Exposure of Type A Badges, UD-802 Dosimeters: Data for Element 2, $Li_2B_4O_7$, with 300 mg/cm^2 Filtration

Location Distance* (cm)		Exposure Time (hr)	Total Dose Measured (mR)	Net Dose Rate Measured (μR/hr)	Ratio of Total Doses (Exp/Mea)
53	(7)	497.5	110.0+/-7.1	188.9	0.9364
	(3)	504	119.7+/-14.6	206.2	0.8739
	(5)	957	181.6+/-11.9	162.0	1.064
	(7)	3976	784.4+/-61.7	180.5	1.015
75	(6)	484.3	66.75+/-5.70	104.8	0.8446
	(3)	504	65.43+/-6.33	98.47	0.9182
	(7)	957	116.6+/-8.4	94.04	0.9434
	(7)	3976	436.1+/-38.8	92.93	1.051
106	(3)	504	45.43+/-1.85	58.79	0.7951
	(5)	957	74.42+/-9.68	49.97	0.8961
	(6)	2062	135.7+/-18.2	48.16	1.040
	(6)	3976	259.2+/-12.8	48.44	1.062
168	(3)	504	25.60+/-0.95	19.44	0.7715
	(8)	812	41.38+/-3.45	18.20	0.8079
	(6)	2062	79.87+/-5.56	21.08	0.9592
	(3)	3976	152.0+/-6.1	21.48	0.9395
237	(6)	769	33.80+/-0.91	9.363	0.7278
	(3)	1680	63.50+/-2.90	16.13	0.8117
	(5)	3976	116.0+/-7.8	12.43	0.9078

TABLE 12

Exposure of Type A Badges, UD-802 Dosimeters: Data for Element 3, $CaSO_4$, with 320 mg/cm^2 Filtration

Location Distance* (cm)		Exposure Time (hr)	Total Dose Measured (mR)	Net Dose Rate Measured (μR/hr)	Ratio of Total Doses (Exp/Mea)
53	(7)	497.5	111.3+/-5.1	196.0	0.9254
	(3)	504	114.3+/-10.3	208.3	0.9151
	(6)	957	187.3+/-10.2	177.0	1.032
	(7)	3976	726.3+/-38.3	169.1	1.096
75	(6)	484.3	60.38+/-3.06	96.18	0.9338
	(3)	504	63.80+/-4.78	108.1	0.9417
	(7)	957	111.9+/-5.0	98.72	0.9830
	(7)	3976	423.6+/-23.4	92.96	1.082
106	(3)	504	40.07+/-4.86	60.99	0.9014
	(6)	957	70.35+/-5.74	54.81	0.9480
	(6)	2062	150.0+/-4.9	58.97	0.9407
	(6)	3976	271.8+/-8.9	54.79	1.013
168	(3)	504	21.77+/-1.75	24.68	0.9072
	(8)	812	35.89+/-1.42	22.16	0.9315
	(6)	2062	80.92+/-6.83	25.47	0.9467
	(3)	3976	140.0+/-6.0	21.64	1.020
237	(6)	769	26.70+/-1.24	11.44	0.9213
	(3)	1680	50.50+/-2.33	13.15	1.020
	(6)	3976	97.53+/-5.41	10.96	1.080

TABLE 13

Exposure of Type A Badges, UD-802 Dosimeters: Data for Element 4, $CaSO_4$, with 1020 mg/cm^2 Filtration

Location Distance* (cm)		Exposure Time (hr)	Total Dose Measured (mR)	Net Dose Rate Measured (μR/hr)	Ratio of Total Doses (Exp/Mea)
53	(7)	497.5	101.7+/-3.5	178.7	1.013
	(3)	504	102.5+/-3.6	185.3	1.020
	(6)	957	172.8+/-6.4	162.4	1.119
	(7)	3976	696.7+/-40.0	162.6	1.142
75	(6)	484.3	58.92+/-3.7	95.23	0.9569
	(3)	504	62.80+/-4.50	106.5	0.9567
	(7)	957	106.6+/-2.4	93.21	1.032
	(7)	3976	400.8+/-16.7	88.20	1.143
106	(3)	504	36.40+/-1.84	54.11	0.9923
	(6)	957	67.10+/-5.0	51.93	0.9939
	(6)	2062	132.3+/-5.4	50.24	1.067
	(6)	3976	248.2+/-13.9	49.82	1.109
168	(3)	504	21.47+/-2.99	24.48	0.9199
	(8)	812	34.16+/-1.95	20.64	0.9786
	(6)	2062	74.65+/-4.88	22.28	1.026
	(3)	3976	131.7+/-7.0	20.52	1.084
237	(6)	769	24.87+/-1.11	9.714	0.9891
	(3)	1680	46.77+/-3.05	10.76	1.102
	(6)	3976	90.52+/-5.54	10.17	1.163

TABLE 14

Exposure of Type A Badges, UD-802 Dosimeters: Data for Element 2 and 3, $Li_2B_4O_7$ with 300 mg/cm sq and CaSO with 320 mg/cm^2

Location Distance* (cm)		Exposure Time (hr)	Total Dose Measured (mR)	Net Dose Rate Measured (μR/hr)	Ratio of Total Doses (Exp/Mea)
53	(14)	497.5	110.6+/-6.0	192.4	0.9313
	(6)	504	117.0+/-11.7	207.2	0.8940
	(11)	957	184.7+/-10.8	169.7	1.047
	(14)	3976	755.4+/-57.8	174.5	1.054
75	(12)	484.3	63.57+/-5.49	100.5	0.8869
	(6)	504	64.62+/-5.10	103.3	0.9297
	(14)	957	114.2+/-7.1	96.08	0.9632
	(14)	3976	430.0+/-31.5	92.67	1.066
106	(6)	504	42.75+/-4.41	59.88	0.8449
	(11)	957	72.20+/-7.64	52.19	0.9237
	(12)	2062	142.8+/-14.8	54.03	0.9881
	(12)	3976	265.5+/-12.4	51.30	1.037
168	(6)	504	23.68+/-2.45	22.04	0.8340
	(12)	812	38.63+/-3.81	20.17	0.8654
	(12)	2062	80.39+/-5.96	23.76	0.9530
	(6)	3976	146.0+/-8.51	21.25	0.9781
237	(12)	769	30.25+/-3.85	10.40	0.8132
	(6)	1680	57.00+/-7.50	15.24	0.9042
	(11)	3976	105.9+/-11.5	11.16	0.9943

TABLE 15

Exposure of Type B Badges, TLD-700 Dosimeters: Data for Position 1, Gamma Radiation

Location Distance* (cm)		Exposure Time (hr)	Total Dose Measured (mR)	Net Dose Rate Measured (μR/hr)	Ratio of Total Doses (Exp/Mea)
53	(3)	504	92.30+/-1.52	174.2	1.119
	(4)	926	193.8+/-6.6	193.1	0.9809
	(6)	1493	302.4+/-8.0	191.8	1.055
	(3)	2111	392.9+/-7.7	179.3	1.103
	(4)	2135	411.7+/-9.9	185.4	1.063
	(3)	3975	721.8+/-15.1	177.7	1.108
75	(3)	504	55.79+/-4.99	101.7	1.070
	(4)	926	112.0+/-11.1	104.8	1.009
	(6)	952	110.1+/-5.4	99.89	1.031
	(3)	2111	231.6+/-6.2	102.8	1.071
	(3)	3759	382.6+/-6.9	97.70	1.120
	(4)	4529	496.2+/-20.3	103.9	1.078
106	(3)	504	36.01+/-4.73	62.48	1.001
	(6)	926	66.91+/-7.45	56.06	0.9979
	(3)	2111	124.2+/-6.3	51.95	1.158
	(6)	2135	134.8+/-5.8	55.62	1.142
	(3)	3759	214.9+/-12.2	53.11	1.221
168	(2)	504	20.96+/- --	32.62	0.9399
	(4)	797	32.99+/-5.62	22.57	1.042
	(6)	2111	64.20+/-9.35	23.54	1.202
	(5)	2135	66.26+/-6.07	23.51	1.275
	(3)	3975	98.87+/-7.11	21.03	1.471
237	(3)	504	15.11+/-3.89	21.01	0.9795
	(3)	769	23.10+/-1.89	10.53	1.125
	(3)	1679	39.24+/-2.41	13.80	1.495
	(6)	2111	36.10+/-2.98	10.23	1.562
	(6)	3759	56.34+/-3.04	10.92	1.825

TABLE 16

Exposure of Type B Badges, TLD-700 Dosimeters: Data for Position 2, Beta and Gamma Radiations

Location Distance* (cm)		Exposure Time (hr)	Total Dose Measured (mR)	Net Dose Rate Measured (μR/hr)	Ratio of Total Doses (Exp/Mea)
53	(3)	504	98.13+/-3.41	183.5	1.053
	(4)	926	193.3+/-14.2	189.7	0.9834
	(6)	1493	303.8+/-18.4	193.3	1.050
	(3)	2111	392.9+/-7.7	183.8	1.103
	(4)	2135	422.2+/-15.0	190.7	1.036
	(3)	3975	728.4+/-5.1	178.8	1.098
75	(3)	504	56.22+/-5.33	100.3	1.062
	(4)	926	112.2+/-6.5	102.1	1.007
	(6)	952	115.8+/-6.7	103.2	0.9801
	(3)	2111	240.7+/-5.5	106.9	1.031
	(3)	3759	385.3+/-2.9	97.76	1.112
	(4)	4529	524.2+/-15.9	108.8	1.021
106	(3)	504	34.65+/-0.84	57.54	1.040
	(6)	926	64.11+/-6.53	50.24	1.041
	(3)	2111	127.3+/-1.4	53.15	1.130
	(5)	2135	133.7+/-3.9	55.50	1.152
	(3)	3759	214.1+/-8.5	52.22	1.226
168	(3)	504	19.87+/-1.86	28.21	0.9914
	(4)	797	36.38+/-2.84	23.58	0.9447
	(6)	2111	68.62+/-9.39	25.35	1.124
	(5)	2135	69.46+/-6.43	25.40	1.216
	(3)	3975	103.6+/-8.3	21.59	1.403
237	(2)	504	13.72+/- --	16.01	1.079
	(3)	769	25.67+/-5.36	10.51	1.012
	(6)	1679	38.68+/-5.10	13.96	1.517
	(6)	2111	39.44+/-2.58	11.53	1.430
	(3)	3759	57.05+/-2.88	10.44	1.802

Figures 4 - 14 plot the results for the Panasonic (Type A) badges as a function of dose rate for each of the filter positions (1 - 4) and for positions 2 + 3 together. Figures 15 - 17 do the same for the two positions of the Type B, Harshaw TLD-700.

DISCUSSION OF RESULTS

Reviewing the tables and graphs a number of observations can be made:

1. Within the uncertainty of the measurements, typically no better than ±5%, there appears to be general agreement between the calculated dose values and the readings for the Panasonic badges, particularly at the higher dose rates.
2. As a general trend the Panasonic readings seem to lie below the calculated values, whereas the Harshaw badge readings, in general, are about 10% higher.
3. As expected, scatter is higher at lower doses, but not consistently so. For instance, comparing elements 1 and 3 for the Panasonic badges, opposite trends are observed, with element 3 reading high at lower dose rates for all total doses, whereas element 1 reads low at all dose rates for all doses. There appears to be no obvious explanation for this effect, which may be a systematic effect of reader operation.
4. For the Harshaw badges, the ratio of calculated to measured dose consistently increased with time of exposure, i.e. measured doses fall off when cumulated over longer times. This effect was most pronounced at the lower dose rates, where lower total doses were received. This effect is illustrated in Fig. 17 for Position 2; as Table 15 shows, the same effect occurred for Position 1. On the face of it, this is a dose-rate dependent fading process; however, conventional fading is usually observed during early exposure and the present effect appears to be a long-term effect.

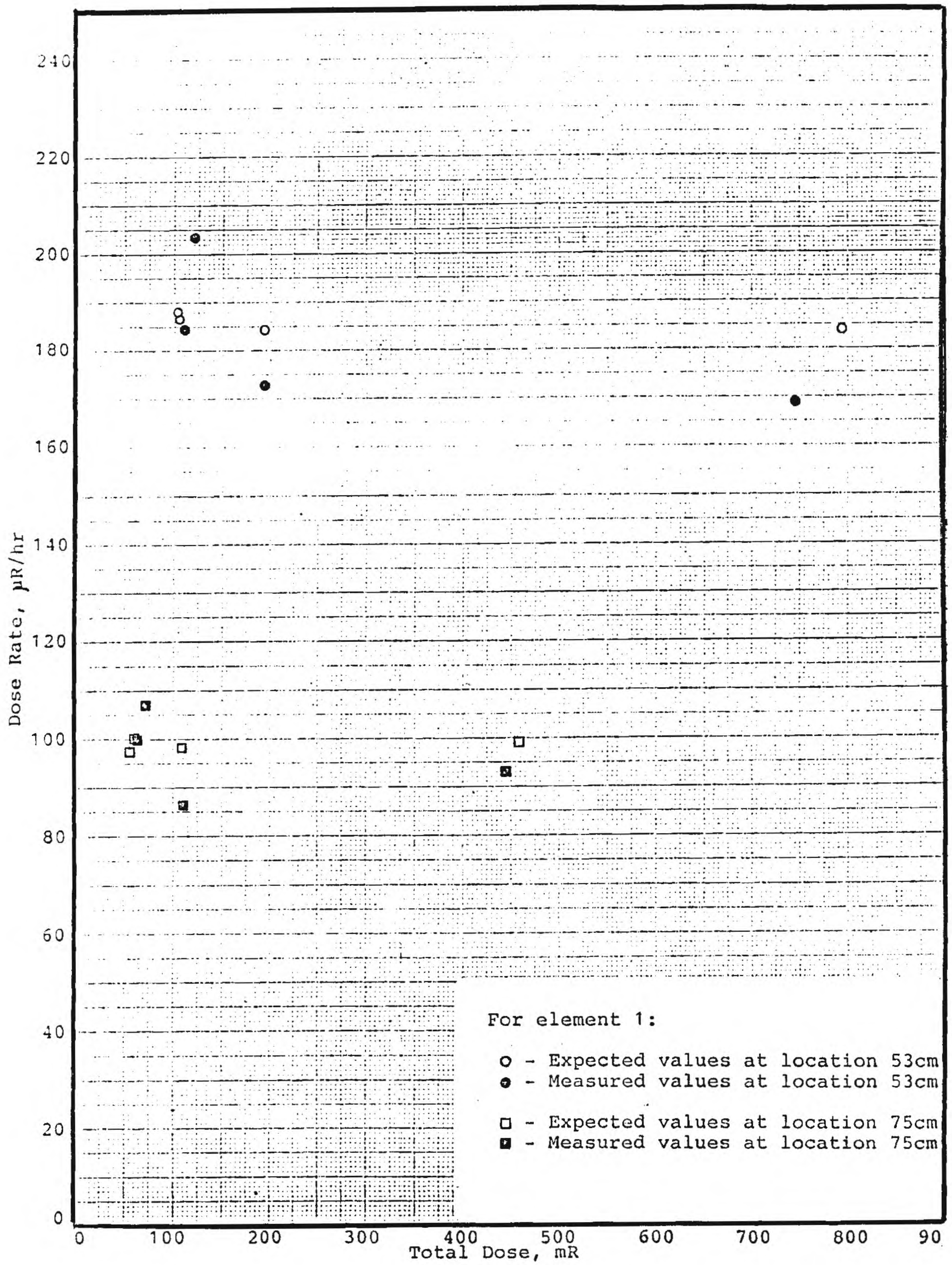


FIG. 4: Comparison of Measured and Predicted Doses, Panasonic Badges Element 1, High Dose Rates

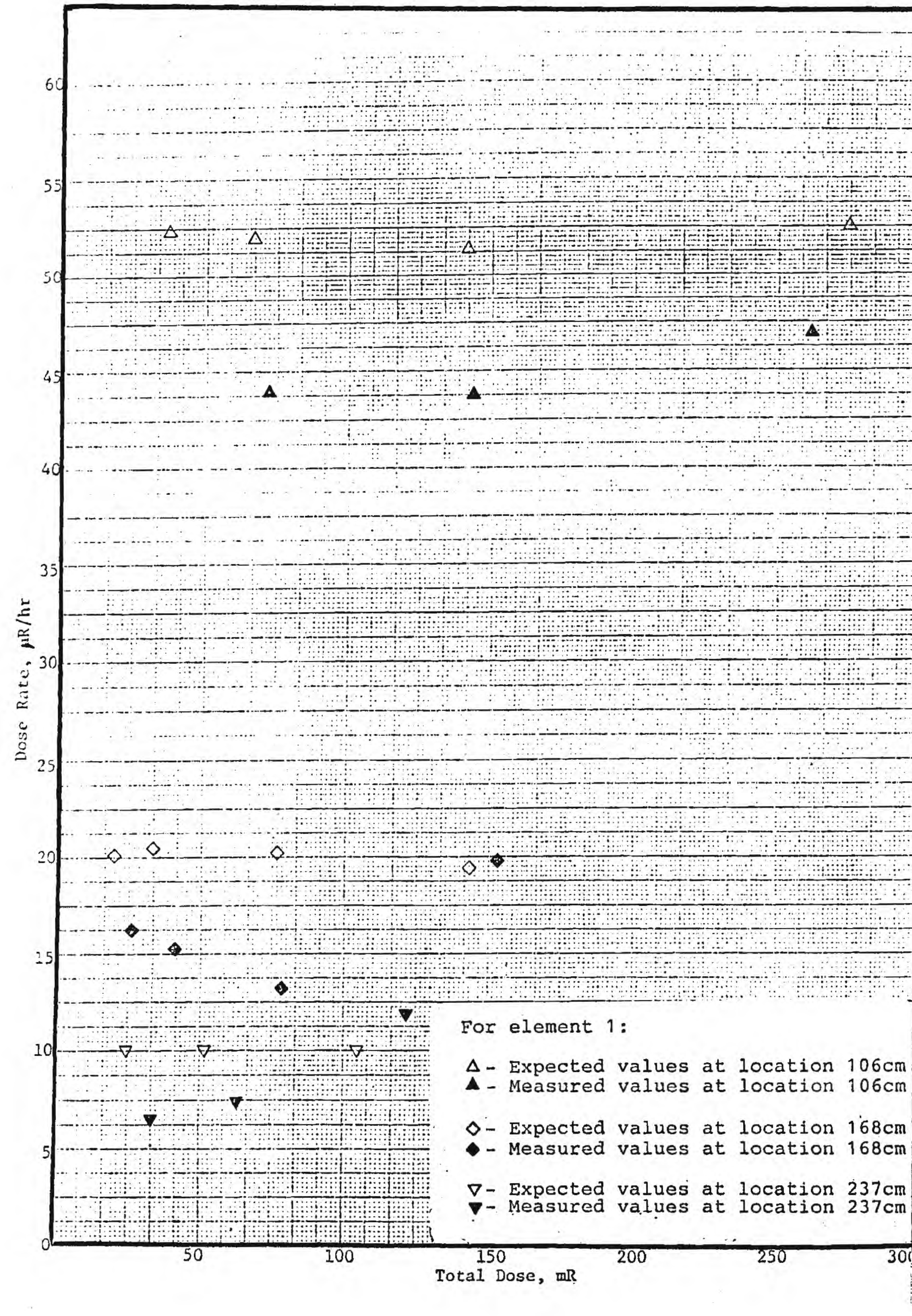
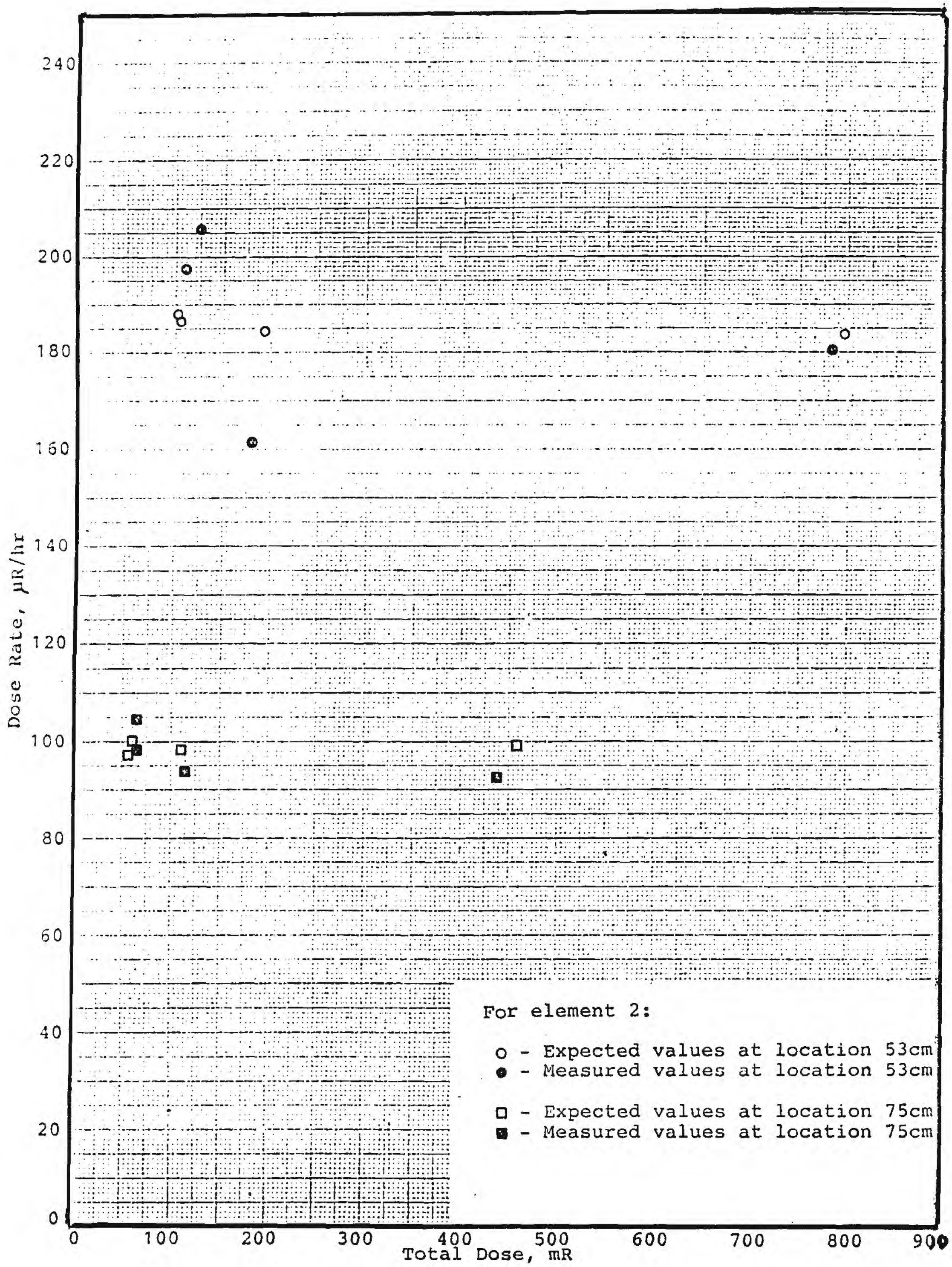


FIG. 5: Element 1, Low Dose Rates



FIG, 6: Element 2, High Dose Rates

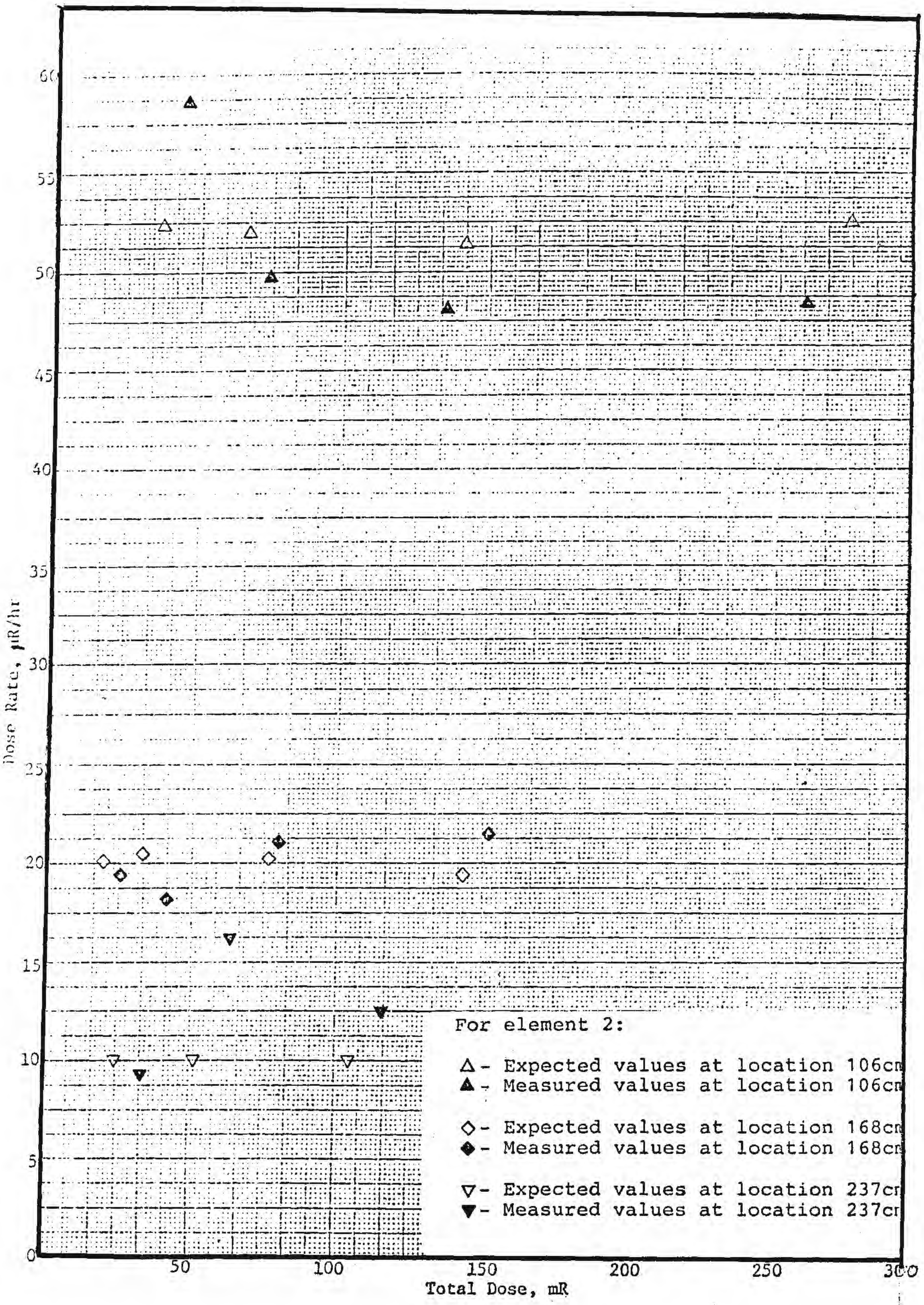


FIG. 7: Element 2, Low Dose Rates

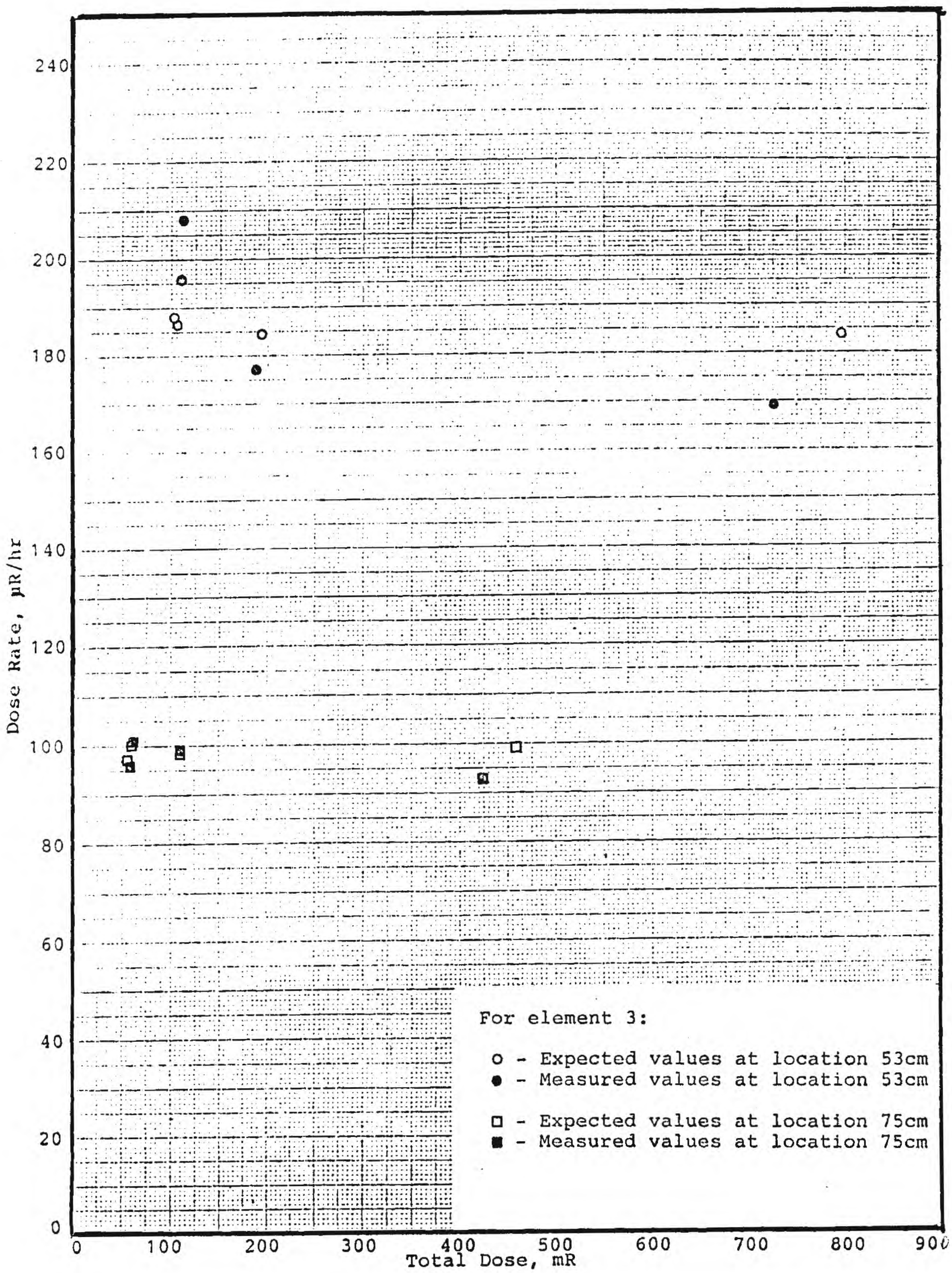


FIG. 8: Element 3, High Dose Rates

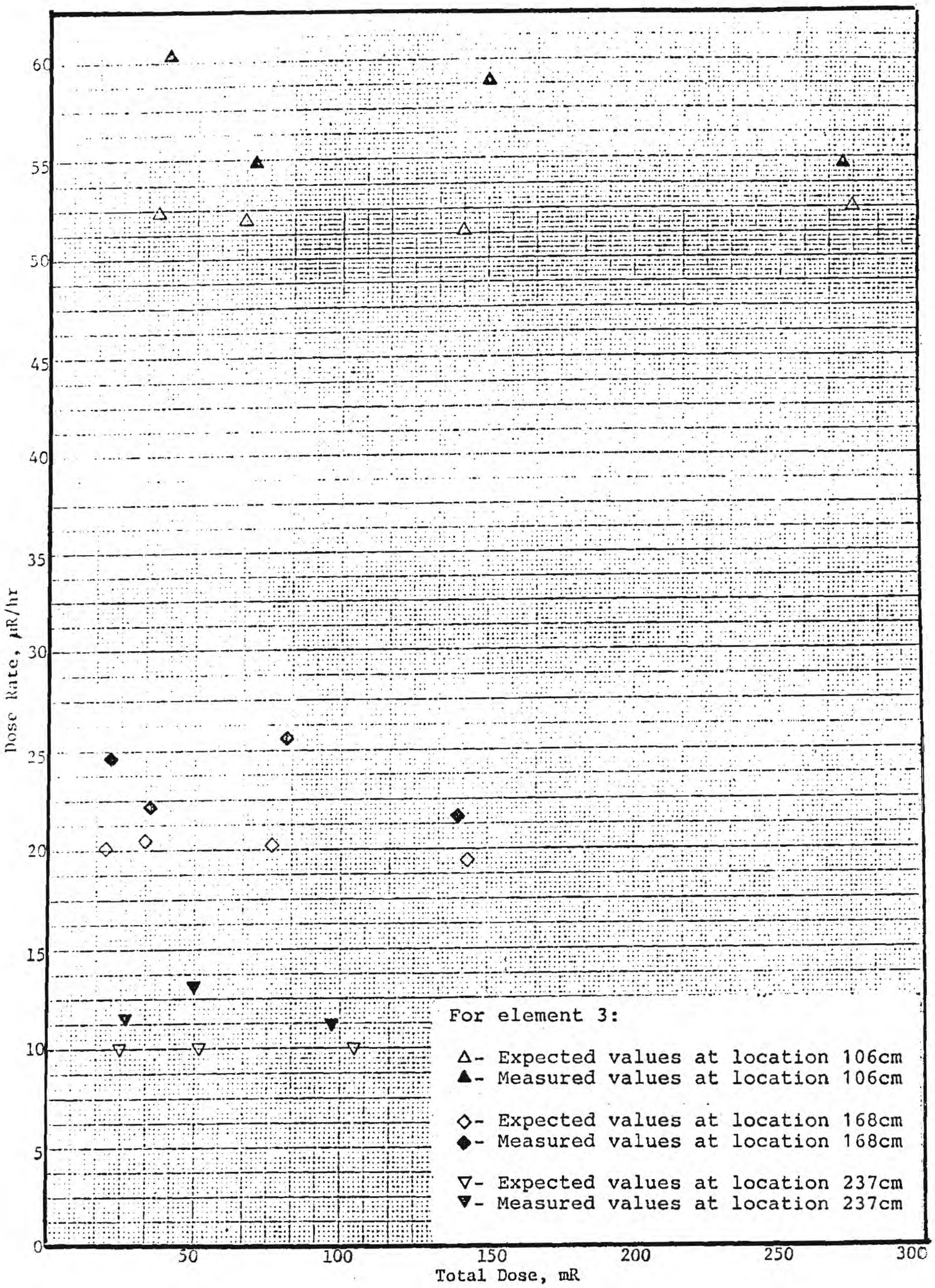


FIG. 9: Element 3, Low Dose Rates

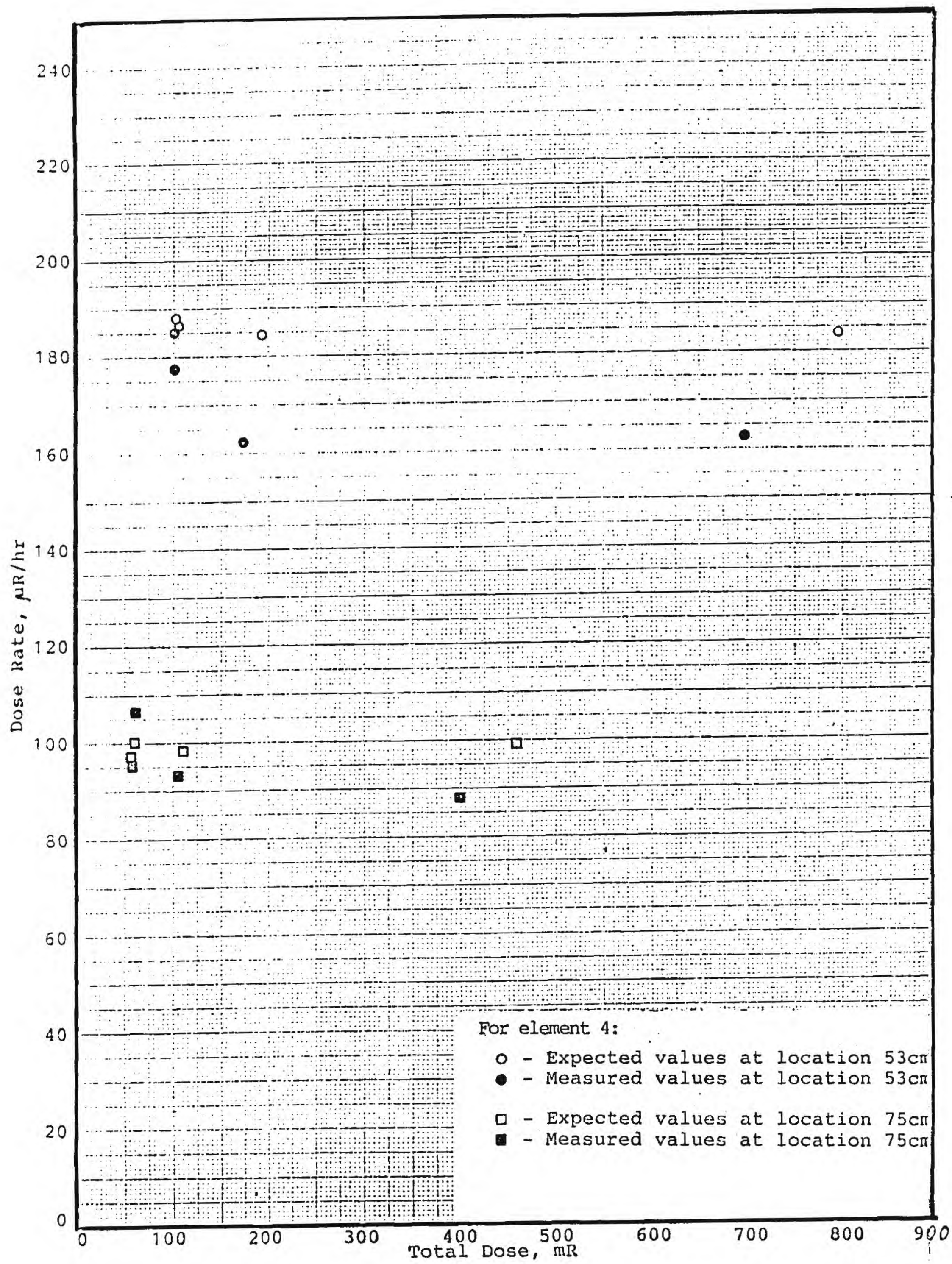


FIG. 10: Element 4, High Dose Rates

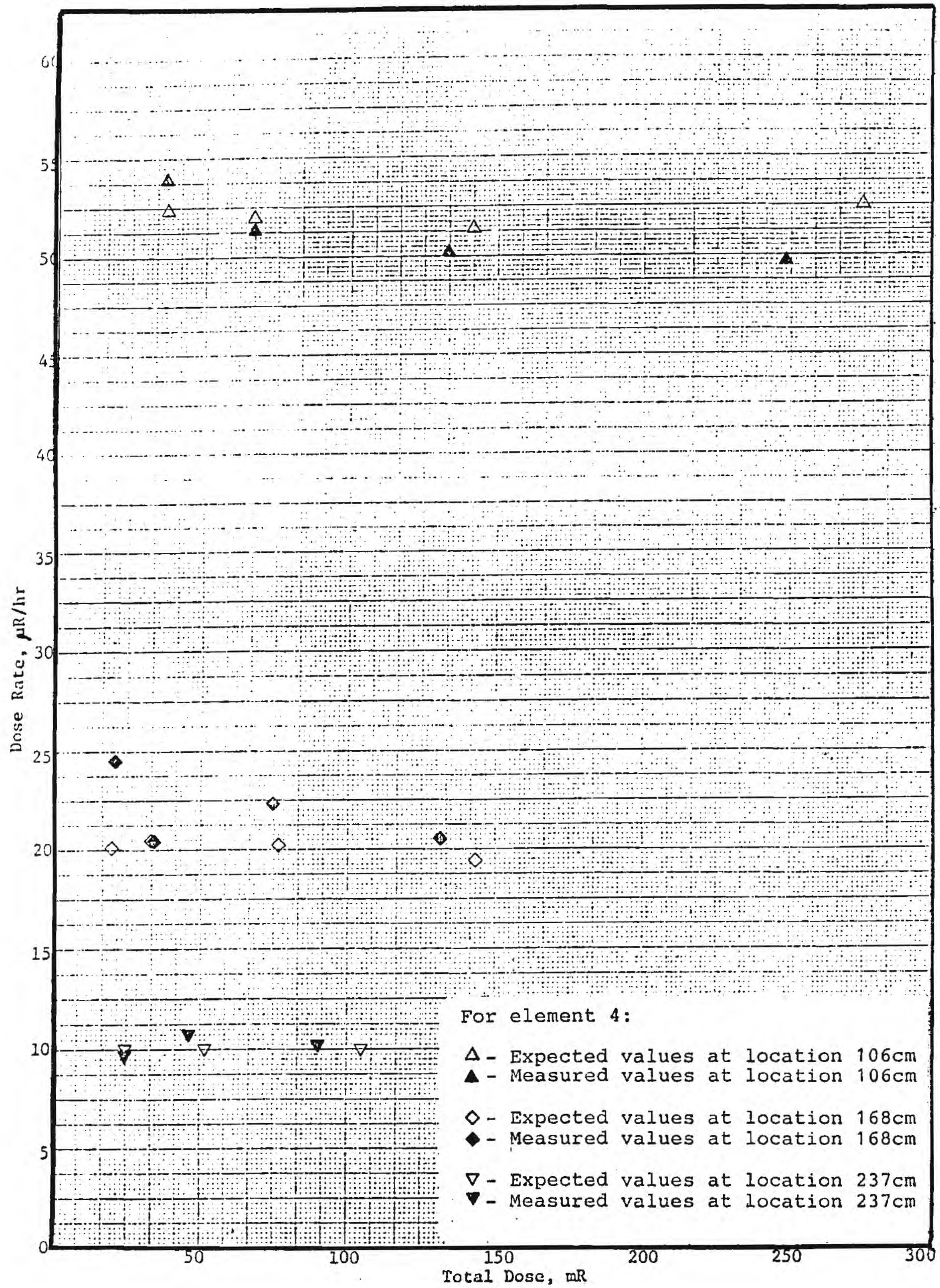


FIG. 11: Element 4, Low Dose Rates

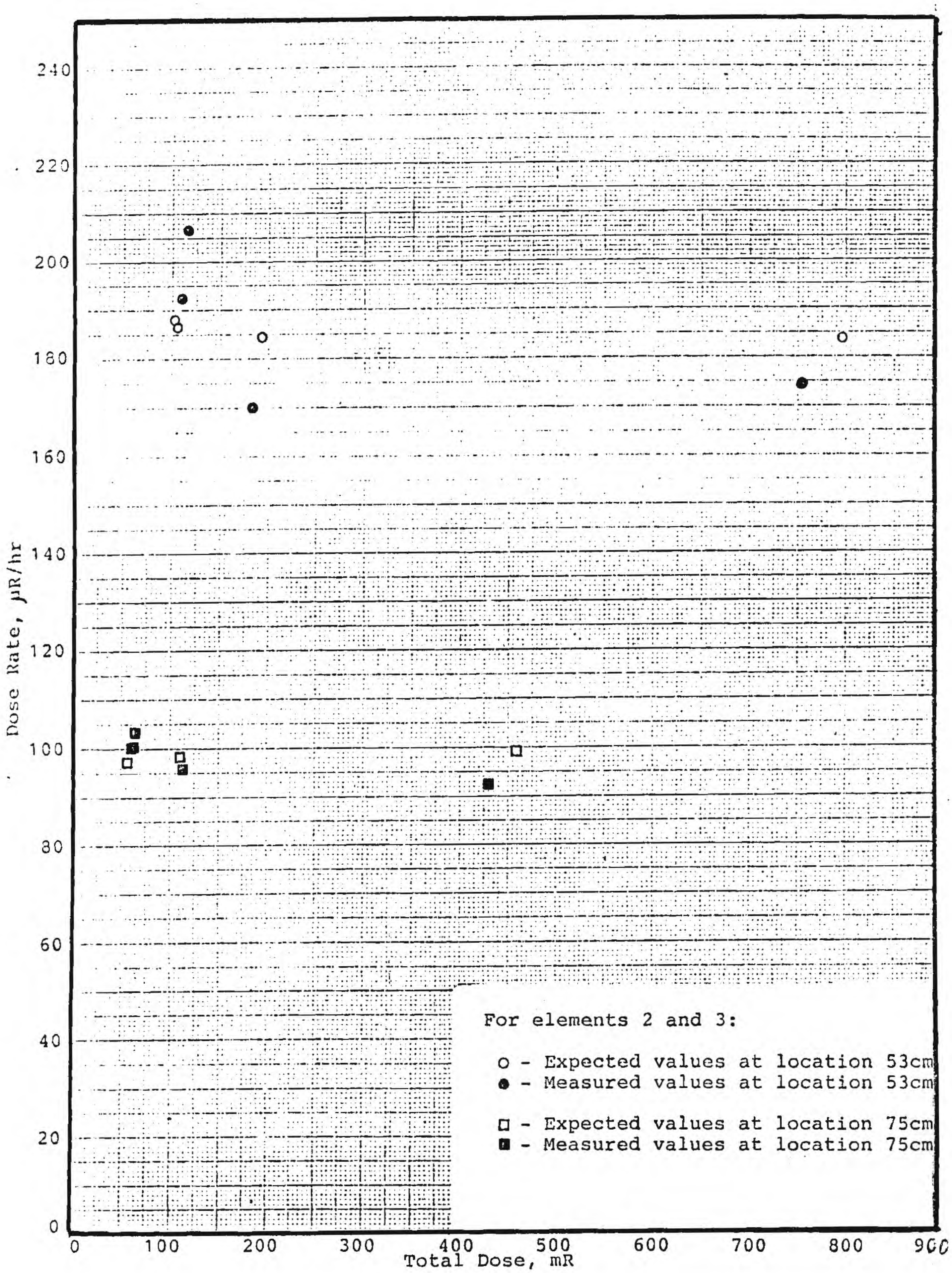


FIG. 12: Elements 2 + 3 Combined, High Dose Rates

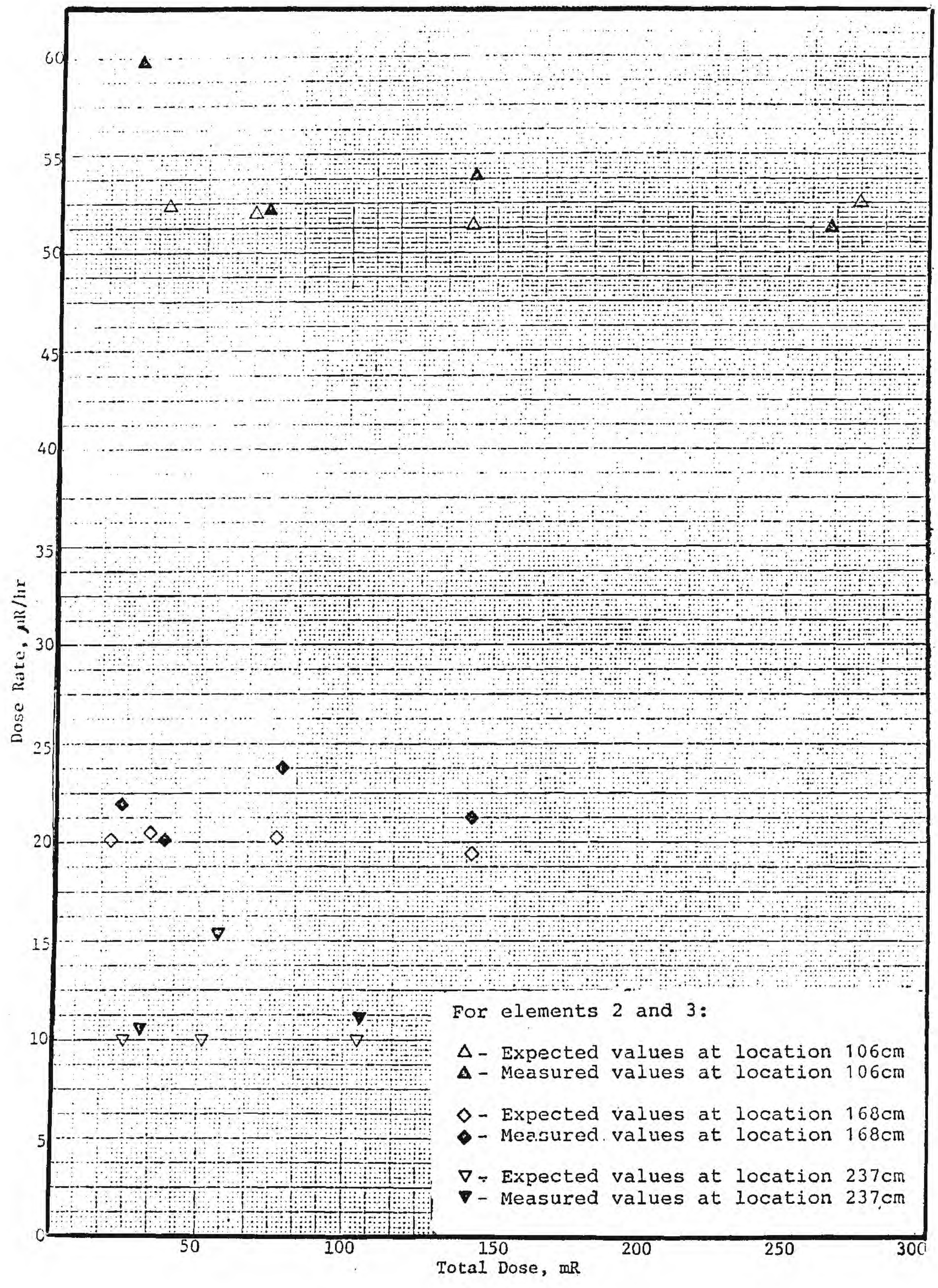


FIG. 13: Elements 2 + 3 Combined, Low Dose Rates

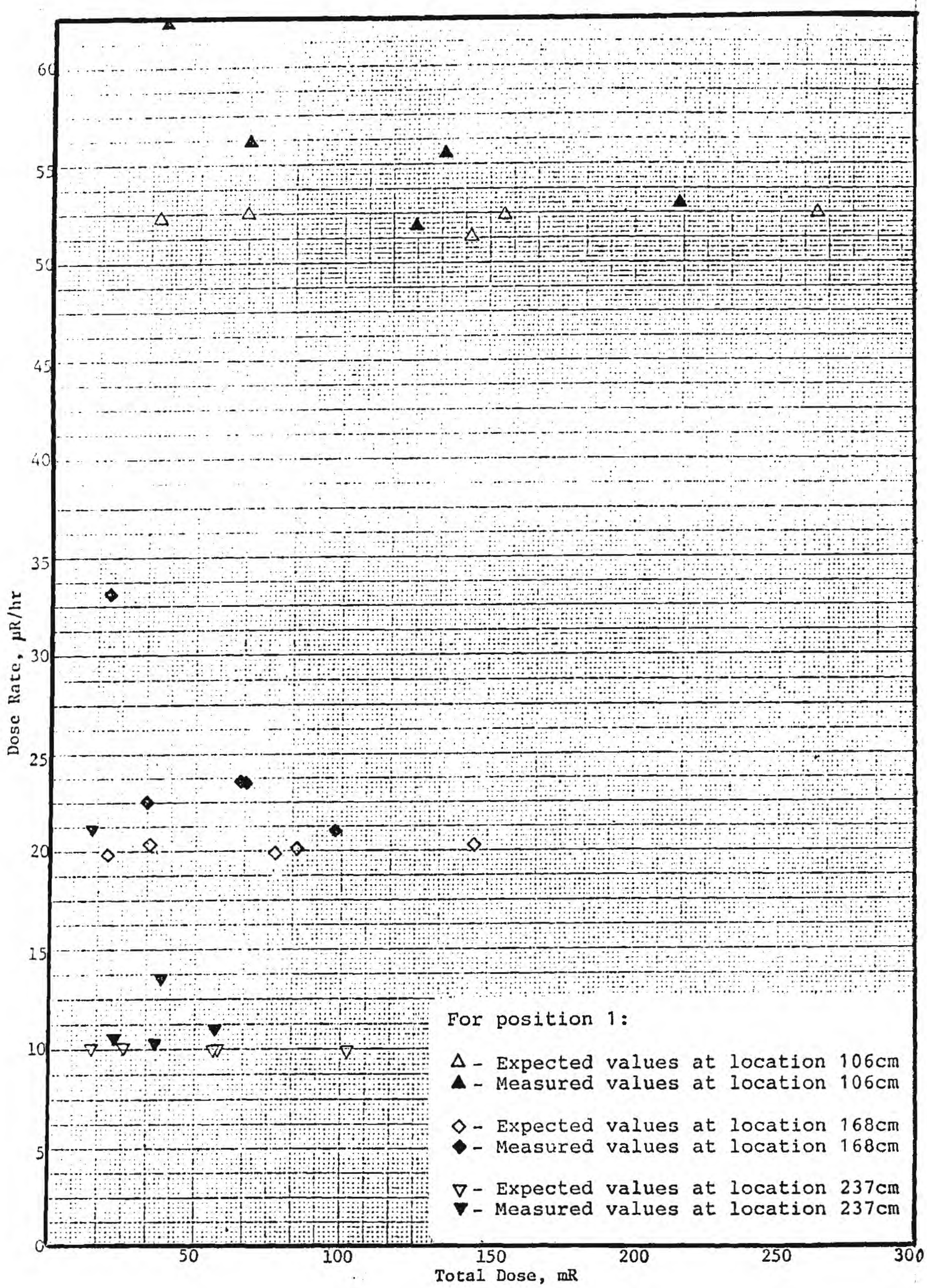


FIG. 14: Comparison of Measured and Predicted Doses, Harshaw Badges, Position 1, All Dose Rates

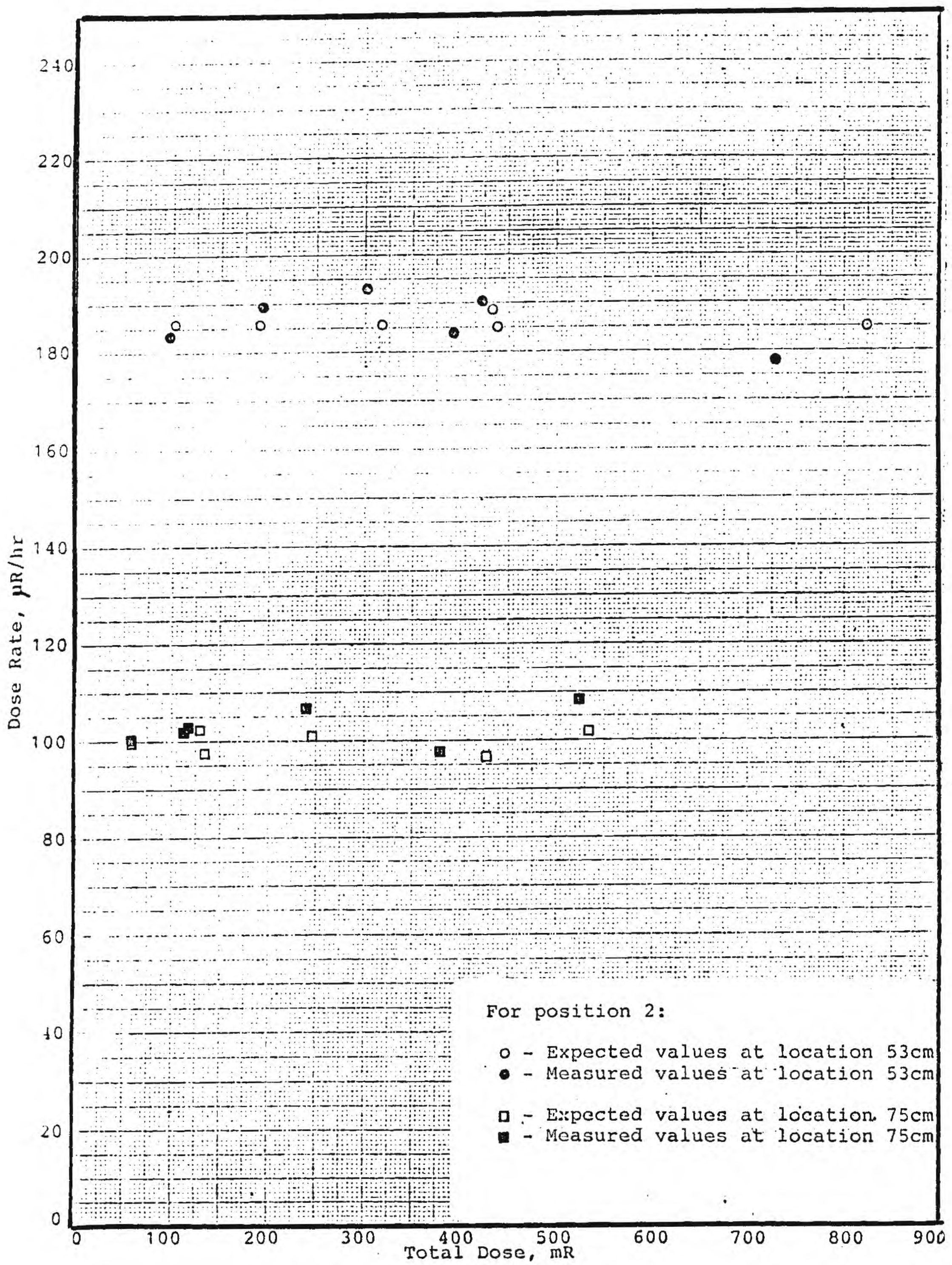


FIG. 15: Position 2, High Dose Rates

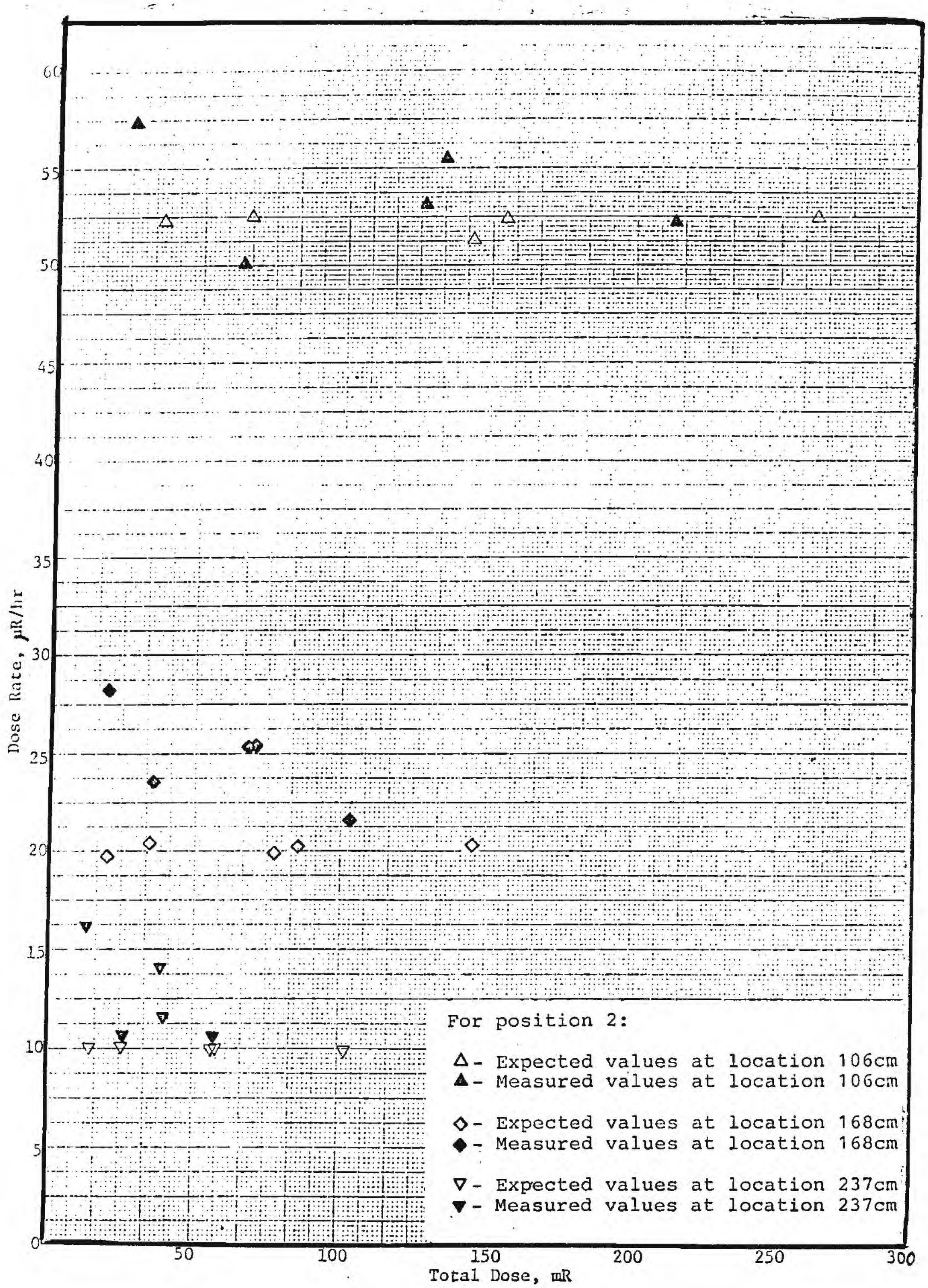


FIG. 16: Position 2, Low Dose Rates

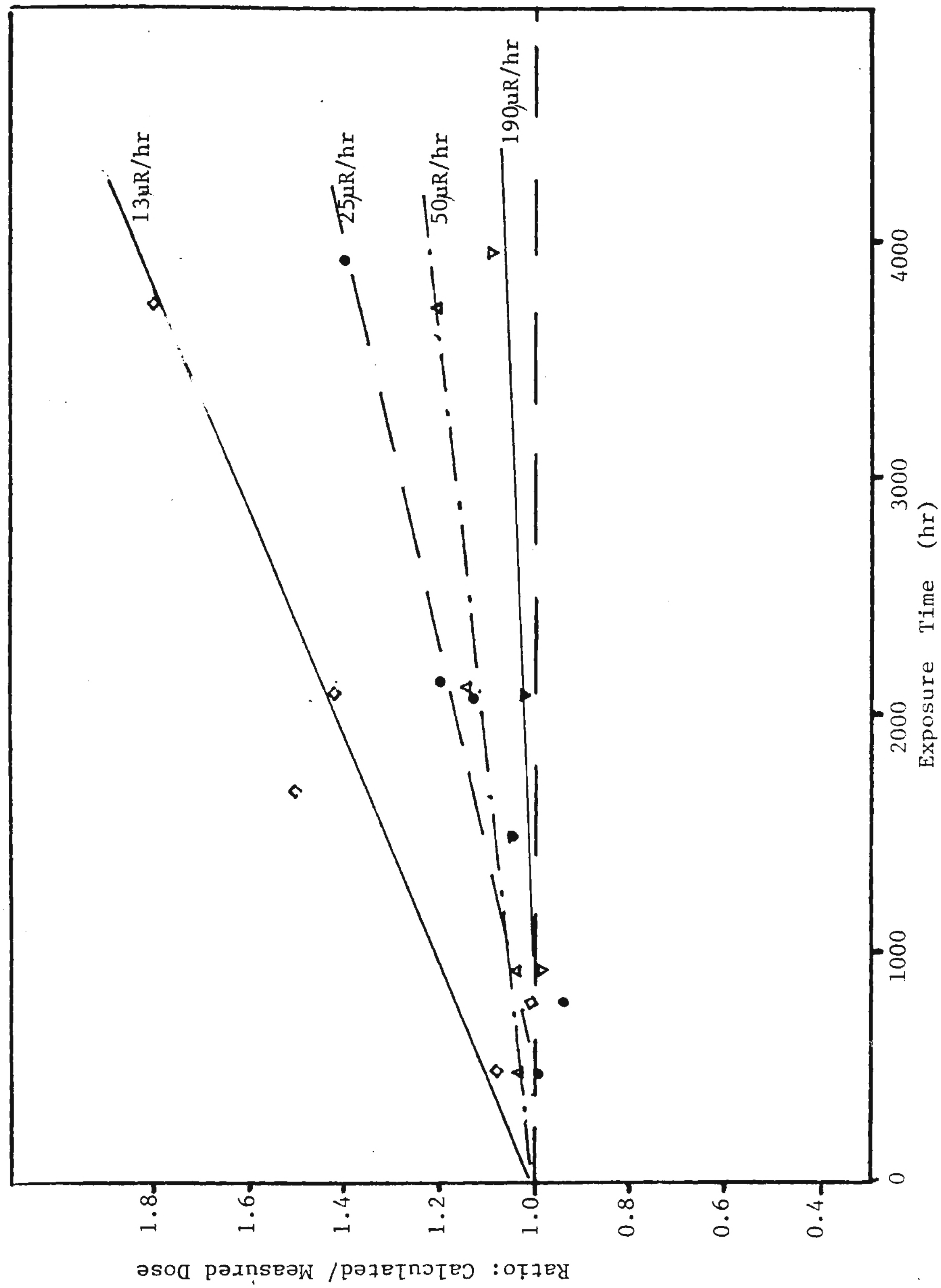


Fig.17: Variation of Measured Dose with Dose Rate (TLD-700)

A similar time-dependent effect is observed in the Panasonic badges, but there it is much smaller and the trend is different. In most cases, there the ratio (calculated/measured dose) starts out below unity, as much as 10 - 15% low, then crosses the line, reaching values 3 - 4 % above it in the end. As Fig. 18 shows, there is a consistent trend, reflecting possibly some fading with time, but its apparent dose-rate dependence may not be statistically significant.

These results confirm to some extent the significance of signal fading. For long term exposures they underline the fact that an error would be introduced into the final dose determination if the evaluation procedure assumes that the exposure took place rapidly at the midpoint of the exposure period. On the other hand for exposures at or near background, the dose-rate-dependent fading becomes immaterial in practice as it gets lost in the rounding off procedure and the reading in most cases would be below the reportable level. In practice, the variability in sensitivity between TLD's in the same batch and inherent uncertainties in the reader will mask the dose-rate dependence shown here.

CONCLUSIONS

The work reported here shows that there appear to be consistent differences in the readings reported for the two types of badges, with the Harshaw badges reading significantly higher than the Panasonic ones. The number of badges tested ensured adequate statistical consistency and for that reason, the observed trends should be accepted as real.

A suspected dose-rate effect was confirmed in the Harshaw badges, particularly at low-dose rates and up into total dose values where statistics are usually considered adequate for good precision. The effect may constitute a form of fading, but the causes are not entirely obvious at this stage. A time-dependent fading effect was also observed with the Panasonic badges, but the effect was smaller and not as clearly dose-rate

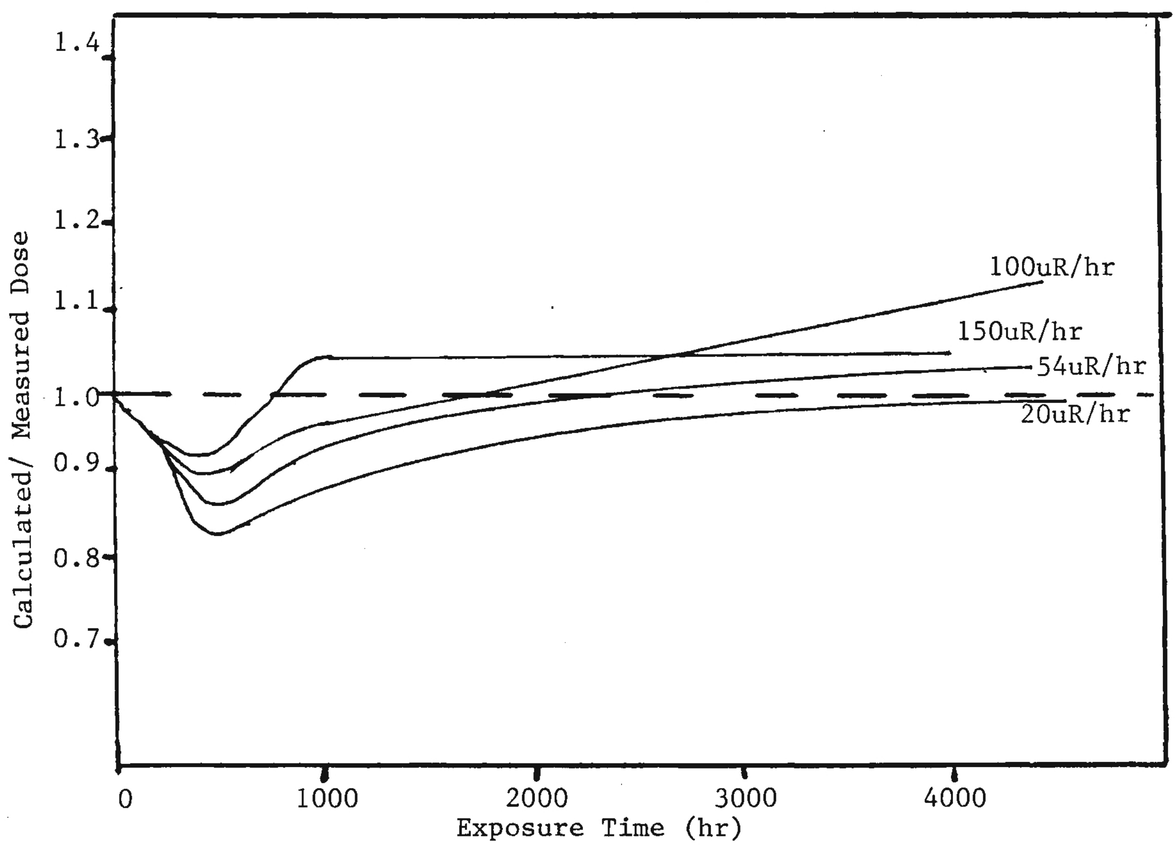


Fig.18: Time Dependence of Panasonic Readings (Elements 2 + 3)

dependent. In fact, at lower dose rates, initial measured doses remained consistently higher for the lower dose rates (Fig. 18), again a conclusion that cannot be fully explained. This effect may have to be included in the evaluation algorithm used in reading the TLD's.

Overall, it would appear that the Panasonic badges give consistent readings within the dose range of interest and any dose-rate dependence would be of minor importance.

REFERENCES

1. C. G. Soares, E. L. Bright and M. Ehrlich, "Difficulties Encountered with Some Intermediate-Atomic-Number Radiation-Protection Dosimeters Irradiated On-Phantom in Low-Energy Photon Beams". Health Phys, 54, 431-444 (1988).

2. E. G. Stassinopoulos, G. J. Brucker, M. C. Stauber, J. H. Stephen, J. Y. Chang and T. K. Sanderson, "Thermoluminescent Detector Performance in Low-Dose Slow-Rate Environments". Appl. Radn. Isot. 39, 303-309 (1988).

3. L. A. R. da Rosa, "The Influence of Temperature and Humidity on the Stability of the Response of Different Thermoluminescent Detectors". Appl. Radn. Isot., 40, 139-145 (1989).

4. G. G. Eichholz, F. J. Clarke and B. Kahn, "Radiation Exposure From Building Materials", in The Natural Radiation Environment III (W. M. Lowder and J. E. McLaughlin eds.), DOE Symposium Series No. 51, Techn. Information Center, US DOE, 1980.

5. Panasonic Operating Manual, "General Considerations for An Algorithm (Section VI C) and An Algorithm for the UD-802 Dosimeter (Section VI D)". Matsuhita Electrical Industrial Co. Ltd., Osaka, 1984.